FACTORS AFFECTING THE REPRESENTATION OF OBJECTS

IN DISTRIBUTED ATTENTION.

BY

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SUMMARY

Our phenomenological experience of what we see around us is of an accurate representation. However, such information is widely distributed in the brain so necessitates that some form of co-ordination of this information takes place to enable a coherent view of the world. The most prominently researched theory is Feature Integration Theory (Treisman, 1993). This proposes that accurate binding is dependent on the current spatial distribution of attention. Individual objects compete for attention via activity in a master map of locations with competition being modulated by grouping processes. When attention is distributed, features are *randomly* selected and a bound object can be perceived to be located at any position within the attentional window. However, there is evidence to suggest that in distributed attention, coarse location information is available and two alternative proposals have been put forward. The first suggests that it is the information from a *unitary* feature that can determine the perceived location of a bound object (Tsal & Lavie, 1988) and the second proposes that the information from all contributing features is *averaged* to provide the location information (Ashby *et al*, 1996). One way to determine which model best represents feature integration is to investigate the contribution each feature makes to the perceived location of a bound object by using the illusory conjunction paradigm in which an object is formed when the visual system binds together individual features from items located in different parts of the display.

Results indicated that in briefly presented displays, perception can be subject to tritan-like shifts in colour space. No support for *spatial averaging* or for the *random* rule was found. Rather, there was a strong indication that the perceived location of illusory objects was sourced from a single feature supporting the *unitary* rule.

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To Graham Hole, for his invaluable support throughout and for making me laugh.

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I'm here because of you all.

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CHAPTER 1: LITERATURE REVIEW

1.1 INTRODUCTION

How is the world perceived as a stable, spatially integrated whole when information from the visual field is widely distributed in the brain? The problem of how we combine such fractionated information into coherent wholes applies to all types of knowledge representation from perceptual to cognitive and lies at the heart of our capacity for symbolic thought (Fodor & Pylyshyn, 1988; Hummel & Holyoak, 1997). The question is longstanding. First noted by Locke in 1690, the issue did not re-emerge until 1961 when Rosenblatt suggested that one type of visual feature must be correctly bound with another type of feature, such as colour (red) with shape (round) to produce a unified representation of that object, an apple. Indeed, Attneave (1974) suggested that

'If colour and form are processed in separate parts of the nervous system, why does one not simply perceive circle, triangle, blue, green without knowing which form has which colour? The simple answer, I believe, is that blue and circle are tagged to the same spatial location' (p 109).

However, is visual binding a genuine problem? While some have suggested that there is no such problem (e.g. Garson, 2001; Leonards, Sunaert, Van Hecke & Orban, 2000), evidence that it is and is not just a theoretical construct revolves around research indicating that at the earliest stages of encoding, retinal co-ordinates are preserved in a variety of retinotopic maps with separate brain regions processing different features of the same object (see Wandell, Brewer & Dougherty, 2005; Wandell, Dumoulin & Brewer, 2007). Such fractionation of the visual scene necessitates that some form of co-ordination of this information takes place in order that a coherent view of the world is achieved. Some of the most convincing evidence that a binding problem exists comes from research showing that we can apparently misperceive an object by binding the features from two different objects in the visual field to form an *illusory conjunction*. When participants are required to report the identity of objects in briefly presented displays of coloured shapes, they often report seeing an object comprised of the shape from one item with a colour from another (see Wolfe & Cave, 1999 for a review).

Some theories of feature binding have focused on temporal properties as a mechanism for binding, suggesting that it is the features located within the focus of attention that are co-activated at a particular moment that are bound (von der Malsburg,

1981; O'Regan & Noë, 2001; Wolff, 2004). Others have proposed a spatial mechanism in which focused attention acts much like a spotlight which selects from a location map the location information of highly activated features contained within its beam. It is these that are bound (Treisman, Sykes & Gelade 1977; Treisman & Gelade, 1980).

By far the most prominent and researched space-based theory to date has been *feature integration theory* (*FIT* - Treisman & Gelade, 1980; Treisman & Gormican, 1988; Treisman & Schmidt, 1982; Treisman, Sykes & Gelade, 1977). During the past forty years, many studies have increased our understanding of the mechanisms involved in feature binding and some have since been incorporated into the model (Treisman 1991, 1992, 2006; Treisman & Sato, 1990). However, a central tenet of *FIT* remains the *spotlight* of attention. Treisman (2006) suggests that the accuracy with which an object can be located is dependent on the size of the attentional window and the number of objects held within its beam. When attention is narrowly focused on one object, a single object file is opened that encompasses all features and provides access to the global properties of shape as well as the boundaries and relationships between individual elements, and correct integration takes place. If the attentional window is distributed across the visual field, a separate object file is opened for each individual feature but because no access to coordinate information is available, individual features may be randomly selected resulting in incorrect binding. Further, at this global level, featural information is pooled within each set of coarsely coded feature maps to provide an average measure of the degree to which each feature value is present.

While *FIT* emphasises the importance of focused attention on the location of an object in order to bind individual features together into a coherent whole, with features being randomly bound when the attentional window is widely distributed, a second model had been proposed arguing that an attentional window is not required for individual features to be bound into a coherent object. Instead, Hazeltine, Prinzmetal & Elliot (1997) suggested that integration occurs via an *aggregate* of location information. An array of feature detectors, each attuned to one feature value, is coded in parallel. If a feature falls within the relevant feature detector's receptive field, it fires with some probability. However, while individual features are initially encoded with some location information, because of the presence of noise during processing, a feature's location will be uncertain. To minimise this uncertainty, a weighted spatial average is taken of all contributing features. Generally, uncertainty is low enough for two features to be perceived as part of the same object, but occasionally the location uncertainty is so

great that a feature from an adjacent object can be perceived to be closer to the first object than that first object's own feature. This results in incorrect binding and the aggregate of the location information will be at the midpoint between both contributing features. Thus, the need for attentional selection is unnecessary because an object, whether real or illusory, will be perceived in a location that is the aggregate of both contributing features (see also Ashby, Prinzmetal, Ivry & Maddox, 1996; Luce, 1977).

Both models indicate somewhat different processes for the initial processing of location information and the contribution that location information from individual features makes to the common location of a complex object. While *FIT* proposes that no location information is available before the focus of attention is applied so that feature localisation is random, the *aggregate* model proposes that the location information from each contributing feature is averaged to determine the perceived location of a bound object.

Two studies have directly tested both models directly (Hazeltine, Prinzmetal & Elliott, 1997; Prinzmetal, 2005). Using an illusory conjunction paradigm, Hazeltine *et al* (1997) found that the location information from a single feature did not contribute to the perceived location of a bound object. Rather, over trials where illusory conjunctions had been perceived, the distribution of location responses was centred over the midpoint between the two contributing features, indicating that a spatial average of the two locations had been made, supporting the aggregate model. Prinzmetal (2005) also found similar results using a simple visual search task. However, their results took no account of foveal bias and it is possible that their findings could be equally well described by a *winner-takes-all* model that allows for this. For example, Schmidt, Werner & Diedrichsen (2003) found that even with stimulus durations as long as 1500msec, the presence of one or more distractors distorted the perceived location of the target. This can be more clearly seen in Prinzmetal's (2005) study, where a clear bias towards the central fixation is apparent.

Therefore the focus of this thesis is to determine which of the three models best describes the contribution that location information from individual contributing features makes to the perceived location of a complex object as reflected in the use of illusory conjunctions as a tool.

1.2 LITERATURE REVIEW

In order to determine what contribution location information makes to the perceived location of an integrated object, it is necessary to address several issues, each of which underpins and contributes necessary information towards answering this question. The first of these is how individual features are encoded prior to selection taking place. This encompasses research examining not only the extent of pre-attentive processes but which parts of the visual field receive high attentional priority and which do not. For example, pre-attentive processes have been discussed at length in the literature and revolve mainly round the question of whether selection is early (e.g. Broadbent, 1955) or late e.g. Deutch & Deutch, 1963). The second issue related to factors concerning the mechanisms involved in attentional priority at the pre-attentive stage of processing. These have generally been assumed to involve both bottom-up and top-down processes (e.g. Cave & Wolfe, 1989). Further, the issue of attentional guidance focuses on whether top-down information can guide attention to a target thereby facilitating the move from parallel to serial processing. The third issue relates to grouping and whether attention is indeed space-based as advocated by *FIT* and is directly relevant to this thesis or is, in fact, object-based (e.g. Duncan, 1984). Closely related to this is the question of whether attention operates on a spatiotopic representation of objects which forms a major part of *FIT* or whether attention selects from an internal object-based representation in which case, the location of an object has no role to play in feature integration (e.g. Tipper, Weaver, Jerreat & Burak, 1994). All of these issues have been challenged in a variety of ways and the literature review discusses each in terms of the subsequent changes that have been made to *FIT* then utilises this information to discuss the issues relating to measures of location.

1.2.1 EARLY DEVELOPMENT OF TWO-STAGE MODELS OF VISUAL PERCEPTION

That individual features cannot be bound to form an integrated object at the preattentive stage of processing is a central claim of all major two-stage models of attention and several behavioural theories have been proposed that purport to resolve the binding problem, many implicating attentive mechanisms (Sagi & Julesz 1985a; Treisman, 1993, 2006; Treisman & Gelade, 1980; Treisman & Sato, 1990; Wolfe, Cave & Franzel, 1989).

Most theories of visual attention were developed from early research into auditory selective attention (Cherry, 1953) and resulted in both early (Broadbent, 1958; LaBerg, 1975) and late (Deutsch & Deutsch, 1963; Norman, 1968) selection models.

Early selection models proposed that selection occurred before stimulus identification. Such models assume that selection is based on low-level features such as location or colour; that the processing system has a limited capacity because the vast amount of information from the environment is just too great to be fully processed; and that stimulus identification is therefore necessarily serial. In contrast, late selection models suggest that selection occurs late in processing, following stimulus identification. Here, underlying assumptions are that selection is based on high-level features such as stimulus identity; that the processing system has unlimited capacity; and that stimulus identification occurs in parallel. However, neither early nor late selection theories alone have been able to account for the extensive body of research. An intermediate view is Treisman's (1964) attenuation model. This proposed that the analysis of a verbal stimulus proceeds hierarchically, beginning with physical cues and moving systematically through syllabic pattern, specific words, basic words, grammatical structure and meaning. If there is sufficient processing capacity to enable complete analysis, then higher level processing is omitted.

The early versus late selection debate in focused auditory attention resulted in a similar approach being taken by researchers into visual selective attention and it has also resulted in a number of different models (see Driver, 2001 for a review). For example, some have suggested that there is equality between early and late selection, so that all items up to and including identity are processed preattentively and in parallel with unlimited capacity (Eriksen, 1966; Eriksen & Lappin, 1965; Eriksen & Spencer, 1969), or with limited capacity (Atkinson, Holmgren & Juola, 1969; Bundesen, 1987; Bundesen, Shibuya & Larson, 1985; Eriksen & Yeh, 1985; Eriksen & St. James, 1986; Rumelhart, 1970; Townsend, 1969). Others have instead proposed that all that is processed preattentively is a signal of activity above a certain threshold to indicate the presence of a feature and either every item in the visual field is processed serially (Atkinson *et al*, 1969; Posner, 1978; Shiffrin & Schneider, 1977; Sternberg, 1967; Treisman & Gelade, 1980) or selectively serially processed (Cave & Wolfe, 1990; Treisman & Sato, 1990; Wolfe, 1994; Wolfe *et al*, 1989). Of these, by far the most influential has been *FIT* (Treisman, 1985; 1986a; 1993; 2006; Treisman & Gelade, 1980; Treisman & Gormican, 1988; Treisman & Sato, 1990; Treisman, Sykes & Gelade, 1977).

In its initial conception, *FIT* was conceived as a two-stage, hierarchical model consisting of a preattentive and parallel stage of processing that preceded an attentive

serial stage as already proposed by many researchers (Selfridge, 1959; Neisser, 1967; Campbell & Robson, 1968; Thomas, Padilla & Rourke, 1969, Rosch & Lloyd, 1978). *FIT* proposed that individual feature values[1] from each feature dimension (curvature, tilt, colour, shape, line-ends and movement) are coded separately by the visual system into individual feature maps using populations of feature detectors. At this stage some primitive grouping processes such as texture segregation and figure-ground grouping take place. This coding is parallel, automatic and rapid with unlimited capacity. However, no cross-referencing between these maps takes place nor is there access to the master map of locations. Thus, information is not shared between individual feature maps and feature dimensions are "free-floating" in relation to one another.

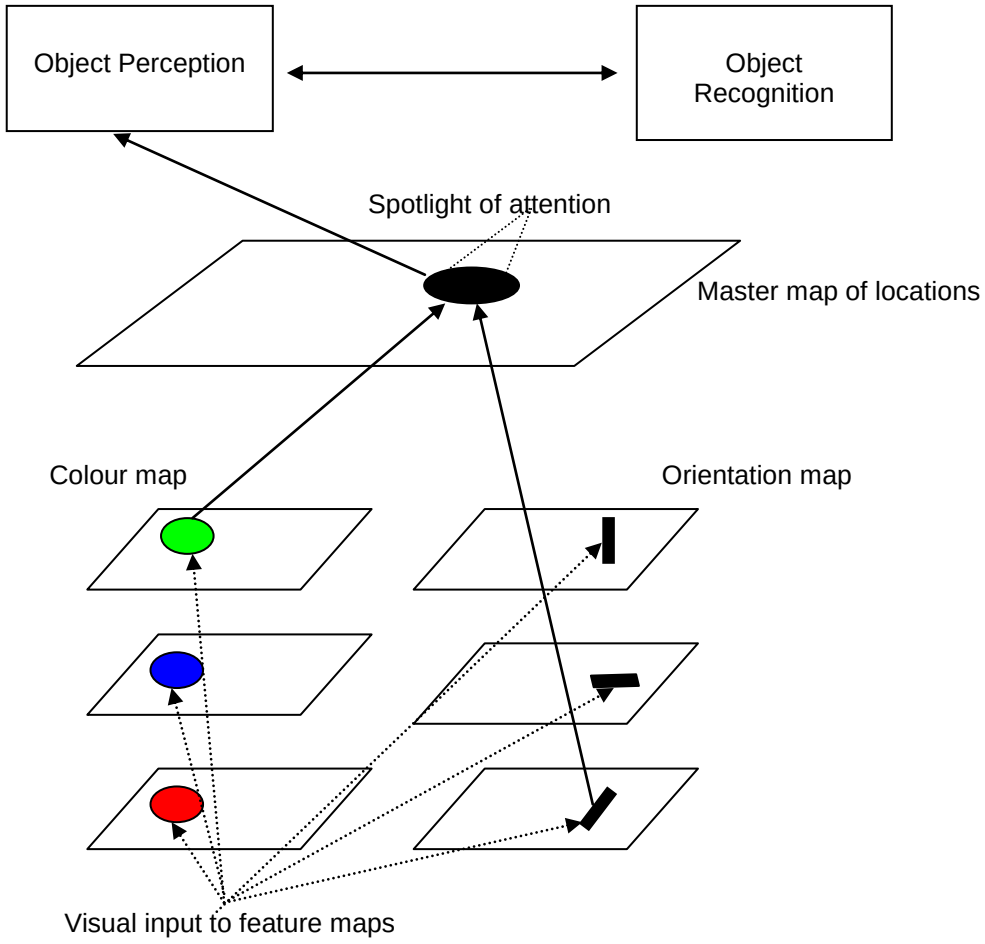

Figure 1.1: Model of feature integration as it was originally conceived by Treisman & Gelade (1980).

[1] The criteria used were taken from both neurological studies (see pp 7-8), and behavioural studies using Gardner's (1974) five criteria for separability. Gardner's criteria were based on the empirical distinction between a) the effective selection of one attribute or feature whilst ignoring variations of another, irrelevant one; b) effortless texture segregation; c) the occurrence of illusory conjunctions : d) "pop-out" and d) the dissociation between detection and identification of individual attributes.

In the second, attentive stage, individual feature maps activate a co-ordinate master map to enable cross-dimensional processing and integration to take place. However, it is not information about actual features that is activated by these co-ordinates, but rather the presence of salient featural discontinuities. In order to recover information, the attentional "spotlight" must then scan the master map of locations to enable access to relevant featural co-ordinates. This then binds information together so that a complex (multidimensional) object can be identified. Binding can be achieved in any of three ways: by focusing attention to the location of the object; via stored knowledge where the various constituent parts or features of an expected object are fitted into "predicted object frames" (Treisman & Schmidt, 1982, p111); and randomly (illusory conjunctions) if there is a lack of either expectation or focused attention. Thus, integrated objects are generally recovered through an attentional, serial scan of the master map of locations and it is this spotlight of attention that "glues" or binds individual features together. Such serial coding is both deliberate and of limited capacity. Thus, in order for the perceptual system to correctly integrate the decomposed features of an object, each of which is stored in functionally independent feature maps at many spatial locations, the allocation of focused attention on each object in turn is required. Once all features are bound via this spotlight of attention and the object has been perceived, a temporary object file is created. This is then compared to other objects held in long-term memory. The object file, a renewable spatio-temporal representation of that object, maintains the object's identity, enabling us to experience a unified object across both space and time. Should the representation decay or be replaced (interference), then features again 'float-free' and may recombine to form an illusory conjunction.

Evidence for initial independence of feature processing by the visual system comes from physiological, neuropsychological and behavioural research. Physiological research indicates that at the earliest stages of encoding, retinal co-ordinates are preserved in a variety of retinotopic maps with separate brain regions processing different features of the same object such as orientation, movement, spatial frequency, texture, depth and colour (see Wandell *et al*, 2005 for a review).

The independence that occurs at the first layer of neurons in the retina continues along axons of the retinal ganglion cells in the optic nerve where information is sent both to the lateral geniculate nucleus (LGN) in the thalamus and to the superior colliculus via the magnocellular (M), parvocellular (P) (Livingstone & Hubel, 1987)

and koniocellular pathways (K) (Cassagrande, 1994). The M pathway carries low acuity information from retinal M-cells relating to movement, location and contrast to the corresponding two M-cell layers of the LGN. The P pathway carries high acuity information from the L and M cone systems relating to long and medium light wavelengths (700 nm and 546 nm) respectively, together with information about object identity, to four P-cell layers (e.g. Andersen, 1987; Goodale & Milner, 1992; Merigan & Maunsell, 1993). The P pathway constitutes about 80% of the total retino-geniculate projections (Perry, Oehler & Cowey, 1984). The K pathway, which mainly carries information from S cones to provide high acuity information for the short light wavelength (435.8 nm), also carries information from diffuse bipolar cells forming chromatically opponent S-(L+M) cells (600 nm). These then project to the thin layers of the LGN that are adjacent to parvocellular layers (Cassagrande, 1994).

Information then proceeds from LGN to Primary or Striate Visual Cortex (area V1). However while the retina, LGN and primary visual cortex produce a distributed representation of the visual field to provide detailed local information, analysis of large scale or global structure of objects in the visual field remains absent. Thus, while many visual properties such as orientation, wavelength, motion and binocular disparity are well represented at each point in the visual field, on reaching area V1, properties of multidimensional objects such as shape, colour, motion and location are not.

Converging evidence for a modular system has also been obtained from neuropsychological studies. For example, some visual agnosic patients who cannot detect shape have been found to have intact colour vision (Warrington, 1985) and achromatopsic patients, who report seeing no colour at all, appear to have intact shape vision (Marshall, 1984) and motion perception (Damasio, Yamata, Damasio, Corbetta, & McKee, 1980). Merigan *et al* (1997) found disruption of colour, shape and contrast sensitivity for stationary objects but intact motion perception and contrast sensitivity for moving objects. Further, Marshall (1984), found specific losses of colour discrimination without loss of form perception in patients who had suffered a CVA (cerebral vascular accident) and Merigan *et al* (1997) found disruption of colour, shape and stationary contrast sensitivity but intact motion perception and drifting contrast sensitivity in a similar patient. It has also been found that in a patient with damage to both the parvocellular and magnocellular pathways, colours could still be discriminated suggesting that the koniocellular pathway was exclusively providing this information (Troscianko *et al*, 1995).

However, evidence for some interaction has been found (DeYeo & Van Essen, 1988). Farah (1994) further argued that the assumption that the effects of brain damage are entirely local is probably erroneous.

A large number of psychophysical and visual search studies also support the notion that basic features of multidimensional stimuli are processed independently (see Wolfe, 2003 for a review). Indeed Garner (1974) proposed a theory of feature independence where an empirical distinction could be made between integral and separable characteristics of various attributes by determining which features could be effectively selected whilst ignoring variations of another. Treisman (1985) suggested that not only could any feature that was processed in parallel and "popped out" in feature search be classified as a primitive feature but also that effortless texture segregation could be used in determining which featural characteristics were processed in parallel, as suggested by Beck (1966, 1967). To date, the list of *primitive* features include orientation, curvature, vernier offset[2], size, direction of motion, depth, colour, gloss, the form primitives of line termination and closure as well as topological constraints such as holes and line intersections (see Wolfe 1998a for a review).

At the second stage of processing, *FIT* stated that focused spatial attention is a prerequisite for object identification. This notion had already been put forward by Sperling (1963, 1967), who proposed a simple serial model where each item is encoded serially until either processing is terminated by a mask or the number of items being encoded and stored in short-term memory (STM) reached capacity. Although Sperling (1967) later rejected this model, research by Eriksen & Hoffman (1972) using groups of letters, showed that only those distractors placed within approximately 1^{o} of the target interfered with target naming although this interference disappeared if the target location was cued at least 150 msec in advance (see also Eriksen & Eriksen, 1974; Eriksen & Yeh, 1985). Posner (1978, 1980) also found that all items in the visual field were processed serially but that focused attention selects a restricted oval region of an image. This enhances detection efficiency for events falling within it but impairs detection of all events falling outside.

However, Eriksen & St. James (1986) suggested that attention operated in much the same way as the zoom lens on a camera and a scale adjustment element was included where size but not location of the attended region changed continuously. For instance, if a participant is required to focus attention on a single location indicated by a

[2] Detecting small differences in the colinearity of line segments.

bar marker, the locus of attention begins in a different state so that the entire display is attended to in preparation for a target's appearance. Attention then zooms in on the indicated location over time. If several adjoining locations are marked, then attention can be distributed to include these but with some loss of speed (Eriksen & St. James, 1986), resolution (Andersen & Kramer, 1993) and interference (see Lavie, 2005 for a review).

While some research appeared to support a serial view of attentional shifts, other studies suggested that attentional shifts do not take more time as the distance to be traversed increases. As the zoom lens model suggests, attention is characteristically focused on only one part of the visual environment but the area covered is variable. While the breadth of attention can be narrow or wide, attention cannot be simultaneously allocated to non-contiguous areas of the visual field. Therefore, attention can only be directed to a single region at any particular time and Treisman & Sato (1990) suggested that this places an important constraint on the flexibility of visuospatial attention.

Initial support for an attentional spotlight came primarily from two types of studies: covert attention, which shows costs and benefits in RTs to targets presented at cued as compared to uncued locations (Posner et al, 1980; Eriksen & St. James, 1986) and flanker task studies, showing the influence of a related distractor on target processing. Incompatible distractors located within 1 degree of visual angle of a foveal target interfered while those at a more distant location did not (Eriksen & Hoffman, 1972; Ericksen & Eriksen, 1974). However, the size of the attentional spotlight had been shown to vary in response to experimental conditions. Jonides (1983) described a two-process model in which attention could be narrowly focused on a single object or distributed across a whole display. Research has also shown that number of distractors, perceptual load, location constancy and difficulty of the foveal task are all ways in which attentional strategies have varied between distributed and focused states (Goolkasian & Bojco, 2001; Laberge & Brown, 1986; Lavie & Tsal, 1994; Lavie, 2005; LaBerge, 1995).

To test their theory, Treisman & Gelade (1980) suggested that if a basic feature can be analysed simultaneously across the entire visual field, that is, with distributed attention, then a single target object that contains a feature also present in the distractors should be detected in the same amount of time regardless of how many other objects are located in the field. However, if a serial search is required, that is, with focused

attention, to analyse a single target with the same basic feature as the distractors, then the time needed to locate the target should increase linearly with the number of objects in the visual field. They showed that reaction times (RTs) for locating target stimuli defined by a single feature not present in the distractors, such as a blue T in a field of green and brown Xs, were relatively independent of the number of distractors present. This, they suggested, indicated that targets possessing a single feature not shared by distractors could be detected in parallel. Information from the same location is collected together by a myriad of receptor cells and transmitted in parallel to form a distributed representation of the many features that make up a single object (see also Treisman & Patterson, 1984). However, for conjunction search, where the target is composed of one feature from one set of distractors and another feature from another set of distractors, such as searching for a green T among brown Ts and green Xs, RTs increased linearly with the number of distractors present in the display. Even with extensive practice, they found that conjunction search remained serial and suggested that this indicated a basic limitation of the system. Conversely, the non-linear or flat search pattern found for feature search suggested that single features were being detected in parallel. They proposed that these findings, indicating a serial, self-terminating search for conjunction targets, fit well with the notion that such targets are coded by means of an attentional mechanism serially applied to each item in turn.

Thus, *FIT* proposed a first parallel stage of processing in which individual features can be detected. However, in order for these individual features to be identified and bound together into a recognisable object, focused attention serially directed to each individual item was required.

1.2.2 FURTHER SUPPORT FOR TWO-STAGE MODELS

A very large body of visual search research has supported two-stage models (see Wolfe, 2003 for a review). Similar support has also been found using other methodologies such as psychophysical thresholds (Morgan, Ward & Castet, 1998; Palmer, Ames & Lindsey, 1993) and studies using a response competition paradigm, which measure the degree to which features of two flanking distractors compete with those present in the target (e.g. Lavie, 1997). Both Huang & Pashler (2002) and Morales & Pashler (1999) used a speeded symmetry detection paradigm where a decision had to be made as to whether or not a display was symmetrical about its vertical midline (see figure 1.2). Morales & Pashler (1999) found that RTs dramatically increased as the number of different colours that were presented increased, suggesting

that participants processed each colour in turn. Huang & Pashler (2002) extended these findings to include size, orientation and spatial frequency and concluded that their results showed that feature binding mechanisms are both effortful and limited in capacity

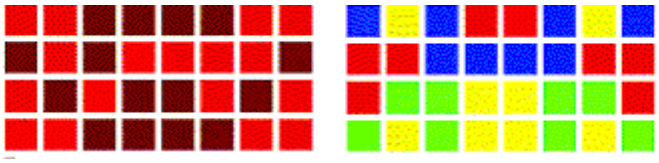

Figure 1.2: Example display for Huang & Pashler's (2002) experiment one.

A further major source of support for all two-stage models was obtained from research using the illusory conjunction paradigm, based on a direct manipulation of attention (see Wolfe & Cave, 1999 for a review). Such research directly tested *FIT*s assertion that if search does not require a location response but detection on the basis of a difference in one feature, then detection can occur without the need to access the target's location information. It is only when a spatial response is needed or when the target cannot be defined on the basis of a single feature dimension that access to the master map of locations is required. This implies two things. The first is that it should be possible to identify a feature without automatically being able to locate it. The second is that when attention is prevented in some way, individual features will be free-floating in that individual features from all items in the display should be detected but not spatially related until attention can be focused serially on each in turn.

Treisman & Gelade (1980) tested this dissociation in their experiments eight and nine. They found that when search was for a single feature (feature search), errors in reporting target locations were large even when accuracy was high for reporting the target's identity. Conversely, when searching for an object comprised of multiple features (conjunction search), accurate reporting of a target's identity depended on accurately reporting its location. The formation of illusory conjunctions has shown that performance in correctly reporting a conjunction target significantly improved over that for single feature reports when the attentional spotlight is focused on the location of an object (Neisser, 1985; Prinzmetal, Treiman & Rho, 1986; Treisman, 1985; Treisman & Schmidt, 1982). Treisman & Schmidt (1982) further investigated this using a dual response, full report paradigm (experiment one). Stimulus displays comprised a single row of two black digits surrounding three coloured letters. These were presented for 120 msecs followed by a mask. Participants were first required to report both digits in

order to divert attention away from the second task, where both colour and shape of the three central letters were to be reported. They found that participants were far more likely to make conjunction errors (by matching combinations of letters and colours from different elements of the display) than they were to make feature errors (by reporting a colour or shape from the display with one that was not present). To eliminate any possibility of guessing or verbal coding, two further experiments (two and three respectively) used a detection task. Treisman & Schmidt (1982) suggested that these results provided evidence that not only are conjunction errors far more prevalent than feature errors but that information about a feature's location, while preserved within spatiotopic maps, is imprecise and not available for further processing without focused attention. Thus, the higher incidence of conjunction errors indicated that features are free-floating in relation to each other, before the focus of attention is narrowed to a particular location.

Nissen (1985) examined conjunctions of features using brief and masked displays of four coloured shapes (experiment two). In the location cue condition, both colour (red, blue green and black) and shape (square, circle, triangle, and diamond) were to be reported and for the colour cue condition both shape and location were reported. Results showed that reports of colour and shape were independent when cued by location but that shape and location were not independent when cued by colour. Thus, accuracy in reporting a target's shape appears to depend on the accuracy of reporting its location. Nissen (1985) concluded that the integration of information across separate feature analysers occurs via a general spatial coordinate system (see also Arnold, Clifford & Wenderoth, 2001; Baldassi & Burr, 2000; Bedell Chung, Ogmen & Patel, 2003; Enns, 2002; Herzog & Koch, 2001; Nijhawan, 1997; Zeki, 2001). Similar results have been found in a two-dimensional computational model (Hinton & Lang, 1985).

Studies combining accuracy with the visual search paradigm have also found that attentional selection always occurs via a representation of visual space. For example, Broadbent & Broadbent (1986) used an RSVP (rapid serial visual presentation at fixation) task where a series of coloured letters (and/or digits) are presented in sequence at speed either at the same location (simple) or alternating on opposite sides of fixation (complex). Responses naming shape based on colour indicated that accuracy was high for both simple and complex presentations. The majority of errors consisted of reporting the shape of the first item that occurred in the same location as the preceding

target. For the simple task, this would be the item presented immediately after the target. For the complex task, it was the second item presented after the target, as this was the first item to occupy the same location.

Similar results have also been found using single or dual response, partial report tasks where types of errors made were examined (e.g. Fryklund, 1975; Nissen, 1985; Snyder, 1972) and with combined partial and whole report tasks where correct responses were analysed (e.g. Tsal & Lavie, 1988). For example, Snyder (1972) used a briefly presented circular array of 12 letters. Participants had to accurately report first the shape and then the location of a unique target. Snyder found that nontarget items were more often falsely reported when they were adjacent to the target. From this he concluded that because attention was directed to the location of the target, an object must first be localised before it can be identified. However, Tsal & Lavie (1988) pointed out that directing attention to the location need not have mediated target identification. Rather, had observers been instructed to select a target by colour (attend to the red target), selection may well be made on this basis or indeed on that of any other feature. They examined this and found that over trials, the perceived location of an individual feature forms a symmetrical distribution around its actual location. Tsal & Lavie (1988) concluded that directing attention to a target's location occurs regardless of the feature dimension used for selection. Further, this effect is not restricted to conjunction targets as suggested by Nissen (1985) and others but includes single features as well (e.g. Prinzmetal *et al*, 1986). Even when irrelevant to the task, it has been found that location affects selection (Tsal & Lamy, 2000). Such results would indicate that spatial location may be of particular importance in the binding of individual features into a coherent object.

An increasing number of neurological studies have also indicated that the visual system separates information about what an object is and where it is located. For example, projections from V1 appear to follow two very distinct but interacting channels, each containing magnocellular, parvocellular and koniocellular information. Evidence for this comes both from primate research as well as human functional imaging, positron emission tomography (PET) and visual evoked potential (VEP) studies (see Milner & Goodale, 2007 for a review). The dorsal channel leads to the posterior parietal cortex and not only provides information about where an object is located (Corbetta, Miezen, Dobmeyer, Shulman & Petersen, 1990; Haxby *et al*, 1991; Kosslyn *et al*, 1993) but mediates visually guided actions (James *et al* 2002; Milner &

Goodale, 1995). The receptive field size of neurons progressively increase as the dorsal channel follows the course of the superior longitudinal fasciculus which encompasses areas V1, V2 and MT (e.g. Eurich & Schegler, 1997; Westheimer & McKee, 1977). Not only are separate subsets of cells in the posterior parietal cortex implicated in visual fixation, pursuit and saccadic eye movements, visually guided reaching and the manipulation of objects (Andersen, Asanuma, Essick & Siegel, 1990) but many cells in the dorsal pathway provide inputs for the continual updating of information relating to both the relative positions and structural features of objects in egocentric space (Newsome, Wurtz & Komatsu, 1988).

The ventral channel leads to the inferior temporal cortex (IT) and provides information about an object's identity, such as its shape, colour and texture (Kosslyn *et al*, 1993; Ungerleider & Mishkin, 1982; Zeki, Watson, Leuck Friston, Kennard & Frackowiak, 1991). The cells in IT appear to be unaffected by changing details but do show high categorical specificity, such as responding only when a face is seen in profile (Gross, 1973) irrespective of viewpoint, retinal image size or colour (Hasselmo, Rolls & Bayliss, 1989; Perrett *et al*, 1991). On reaching the extrastriate cortex, the receptive field size of neurons in the ventral channel also increases steadily. For example, in area V4 neurones' receptive fields are several degrees wide while in IT they have a receptive field that can include the entire central visual field, up to about 30^{o} (Desimone, Albright, Gross & Bruce, 1984). This increase is consistent with the notion that the cells in IT generalise their response across the visual scene and code features of an object independent of its location (Gross, 1973). Thus, object-based descriptions of the ventral stream appear to form the basic raw material for recognition memory and other long-term representations contributing to the comparison of real-time visual inputs with internal representations stored in neighbouring regions of the medial temporal lobe (e.g. Eskandar, Richmond & Optican 1992). It has also been proposed that feature binding occurs in the ventral channel and further that processing of individual features from the same object occurs in the parvocellular pathway whereas features from adjacent objects are processed in the magnocellular pathway (Davis, 2001; Davis, Driver, Pavani & Shepherd, 2000).

Such research indicates that in order for binding to take place, information from the ventral and dorsal pathways must, at some stage, come together to link an object's identity to its location. Two such areas have been found. Firstly, Baizer, Ungerleider & Desimone (1991) found that both streams project to the anterior part of the superior

temporal sulcus which then projects into the limbic system. Secondly, Goldman-Rakic (1987) found that both streams also project to the dorsolateral pre-frontal lobes: the dorsal stream projects to area 46 and the ventral stream to a more orbital region that is beneath and slightly posterior to area 46 (see also Simon-Thomas, Brodsky, Willing, Sinha & Knight, 2003).

Evidence from neuropsychological studies has shown that deficits in spatial attention also result in feature binding problems (see Robertson, 2003 for a review). The earliest came from studies of patients selectively impaired for either object recognition or spatial vision (Lange, 1936). For example, a correlation between performance in a spatially cued task and the incidence of illusory conjunctions has been shown for patients with damage to the left hemisphere (Arguin, Cavanagh & Joanette, 1994; Cohen & Rafel, 1991). Further, such patients can detect a single feature, such as shape or colour in the area of the visual field that is contralateral to the damaged hemisphere, but they cannot detect objects defined by a conjunction of features such as shape and colour (Eglin, Robertson & Knight, 1989; Estermann, McGinchey-Barroth & Milberg, 2000). Similar problems have been found in patients with unilateral right hemisphere damage (McCrae, Buxbaum & Branch Coslett, 2006; Newcombe & Russell, 1969). For example, McCrae *et al* (2006) studied a patient with unilateral right hemisphere damage and found that while parallel search remained intact, a serious deficit in serial search was evident. Not only was there a failure to detect multidimensional objects but there was a high incidence of featural miscombinations for both colour and form, although the incidence of illusory conjunctions was significantly decreased if interletter distance was increased (see also Humphreys, Cinel, Wolfe, Olson & Klempen, 2000).

More extreme problems have been found in patients with symmetrical bilateral lesions in the posterior parietal lobe and centred in the angular gyrus (Rizzo & Vecera, 2002) resulting in the visual world being perceived erratically as a series of isolated objects. Such damage results in an apparent inability to localise, individuate or select a location for attention (Bálint syndrome: Bálint (1909), translated by M. Harvey (1995)). Only a single object can be perceived at any one time (dorsal simultagnosia). As there is no peripheral sensory loss, it appears to be an attentional deficit (Humphreys & Riddoch, 1993). Spatial information is almost completely lost so that while patients can recognise a single object they can neither reach for it under visual guidance (optic ataxia) nor describe its location (ocular apraxia).

Luria (1959) found that such patients are only able to see one disc when two separate discs were presented simultaneously. However, when the two discs were connected by a line, both discs were perceived as one object. Thus, it would appear that neglect of distinct regions of the visual field is dependent on whether they are linked by a common object to other regions. However, because this deficit is also apparent in displays too brief to permit eye movements, it is unlikely to be due to overt orienting (Driver & Mattingley, 1995). Farah (1990) suggested that simultagnosia may simply be a form of neglect consistent with bilateral lesions so that difficulty may be found in disengaging covert attention from an object in order to shift it in any other direction. However, discrepancies between different Bálint patients indicate that more than one processing impairment may underlie the syndrome (see Rizzo & Vecera, 2007 for a review).

If feature binding does require spatial attention to correctly bind individual features as *FIT* proposes, then the almost total lack of location information available to Bálint patients should result in a high incidence of randomly combined features. Friedman-Hill, Robertson & Treisman (1995) examined cross-dimensional conjunctions in a Bálint's patient and found that when presented with two coloured shapes, 38% of trials resulted in illusory conjunctions even with exposure times of up to 10 seconds. They suggested that the results were consistent with *FIT* in that illusory conjunctions are caused by impaired spatial attention. Similar results have also been obtained for motion and shape, and colour and size (Robertson, Treisman, Freidman-Hill & Grabowecky, 1997; Bernstein & Robertson, 1998).

Such evidence suggests that, as found in behavioural studies, patients with unilateral neglect also make illusory conjunctions when attention is diverted to one side of the visual field. For patients with bilateral damage, while spatial information is recorded (Robertson *et al,* 1997*),* the spatial representations required to bind individual features in multi-item displays are compromised (Kim & Robertson, 2001). Robertson (2003) suggests that the combined deficits of Bálint's syndrome are consistent with the notion that both feature binding and object individuation depend on an intact representation of space and that precise spatial information is required to identify a multidimensional object. However, if this were the case, a much higher incidence of featural miscombinations would be expected. The fact that in Friedman-Hill *et al's* (1995) study, the Bálint's patient could correctly identify a conjunction target in 62% of trials indicates that precise spatial information is not required in order to identify an

object comprised of multiple features. Certainly, McCrae *et al* (2006) found that a similar patient not only made illusory conjunctions in 54% of trials with unlimited exposure time but that correct reporting was inversely related to distance. This result is consistent with the coarse coding hypothesis (Ballard, 1986; Eurich & Schwegler, 1997).

Additional physiological evidence suggests that while independence of featural processing is apparent even in the extrastriate cortex, the processing of stimuli is facilitated within the attentional spotlight. For example, Zeki *et al*, (1991) found that component features are processed in separate regions of the brain, each containing one or more independent maps of the visual field. Over twenty-five specialised areas in humans, arranged hierarchically, have been identified to date. For example, area V3 and V3α respond to shape, V4β to direction, V5 to spatial location and movement (Ungerleider & Mishkin, 1982), the lingual and fusiform gyri respond to both colour and form (Zeki *et al*, 1991) and colour processing is also identified with the dorsolateral occipital cortex (Corbetta, Miezin, Dobmeyer, Shulman & Petersen 1991). However, sensitivity in these areas has been found for features other than the preferred one (e.g. Cavanagh & Anstis, 1991; DeYeo & Van Essen, 1988; Ghose & Munsell, 1999). Several studies have shown that up to 90% of cells in V1 and approximately 50% of V2 and V3 cells that are preferentially responsive to colour also encode both orientation and direction of motion (e.g. Lennie, Trevarthen, Van Essen & Wassle, 1990; Gegenfurtner, Kiper & Fenstemaker, 1996). More particularly, it has been shown that some location sensitivity is present in ventral shape representations (Desimone, Schein, Moran & Ungerleider, 1985) and selectivity for shape representations has been observed in the dorsal pathway (Sereno & Maunsell, 1998). Event related potential (ERP) studies have shown increased activation in multiple areas of the extrastriate cortex, with no such activation in V1 when attention is focused on a specific location, (e.g. Mangun, Hillyard & Luck, 1993), when focused on individual features (Corbetta *et al*, 1991) and when identification of a specific object is required (Luck, Fan & Hillyard, 1993). This flow of visuo-spatial information to multiple areas of the extrastriate cortex may be facilitated by projections from the pulvinar nucleus of the thalamus (LaBerge & Buchsbaum, 1990). Such studies indicated that an early selection mechanism may facilitate processing of stimuli falling within the attentional spotlight.

It can be seen that a vast array of research from behavioural studies using not only the visual search paradigm but illusory conjunctions, RSVP, psychophysical

thresholds and response competition provided confirmation of the strict dichotomy between the two stages of processing advocated by *FIT*, converging evidence had also come from both neurophysiological and neuropsychological research.

1.2.3 PROBLEMS WITH TWO-STAGE MODELS

1.2.3.1 PARALLEL OR SERIAL PROCESSING

While evidence for a strict dichotomy between parallel versus serial processing was initially compelling, subsequent research has shown that observed differences in search performance were not always associated with such clear distinctions (see Horowitz & Wolfe, 2001). For example, it has been argued that parallel processing and preattentive texture segregation are inadequate as single determinants for defining a basic feature. Both Wolfe (1992a) and Snowden (1996) found stimuli that produced effortless texture segmentation but not efficient search and vice-versa.

Initially, Treisman & Gelade (1980), by looking at feature discriminability, suggested that varying difficulties in feature search did not rule out qualitative differences between feature and conjunction search. For example, in experiment three, Treisman & Gelade (1980) used a single feature (ellipse) of five increasing sizes. Nontargets were always sizes 2 and 4. Either a target of size 1 (small) or size 5 (large) was used that was similar to only one of the two nontargets, or a size 3 target was used that was similar in size to both nontargets. Further, a target could be either present or absent. As expected, they found an effect of set size on search time although all search functions were found to be nonlinear and negatively accelerating. They concluded from this that even though search was difficult, it remained parallel. To explain increasing RTs for difficult feature search, they surmised that the presence of a highly discriminable target would record a greater degree of activity than nontargets on a particular feature map. However, while differences in activity will be far larger for a *target present* than for a *target absent* display containing few items, as the number of items in the display increases, proportionally less activity will occur for *target present* displays than *target absent* displays. They proposed that this resultant difficulty in detecting the target in large displays would necessitate the division of the display into featural subgroups for serial processing.

While Treisman & Souther (1985) also stated that it was the discriminability between target and distractors that determined how easy search would be, they established that search performance was not solely dependent on saliency. They had found that search for a target that included an additional feature not present in the

nontarget (such as a Q among Os), provided flat search functions, whereas a target defined by the absence of a feature present in the non-targets (such as an O among Qs) provided a steep search function (see Garner, 1978). Thus, while the presence of a unique feature in the target allows for fast, parallel search, searching for a target defined by feature absence is slow, serial and self-terminating. As a result, Treisman & Souther (1985) proposed a preattentive procedure that recorded not just the presence of a feature but the amount of pooled activity of all features contained within each feature map. To account for the search asymmetry found, they suggested that for the *target absent* condition, targets without the added feature (O) would record less activity than targets with the added feature (Q) and the display would need to be divided into smaller featural subgroups than would be required for *target present* trials in order to detect the target. Thus, search asymmetry occurs not only because of the different amounts of activity recorded for both types of trials but because of the change in search strategy used for the two conditions. Similar asymmetries have been found for moving and stationary items (Royden, Wolfe & Klempen, 2001); colour (Treisman & Gormican, 1988); and orientation (Foster & Ward, 1991).

Treisman & Gormican (1988) tested the notion of pooled activity using a number of different stimuli. They not only found evidence for asymmetries between easy and difficult searches but also that feature search could be critically affected by differences in similarity between targets and nontargets. Nevertheless, from their findings, they did suggest that rather than the summing of activity proposed by Treisman & Souther (1985), activity is instead averaged via a process of mutual inhibition between different feature detectors. Thus, each point on a given map reflects the activity of a single feature detector but as the number of feature detectors increases within a single map, each now receives a corresponding and increasing number of inhibitory inputs resulting in mutual inhibition.

In light of the earlier research, Treisman (1988) suggested that *FIT* could be modified to incorporate a strategy where a unique feature sufficiently differentiates nontargets into two distinct subsets, resulting in high discriminability. In this case, spatial selection would control activation levels of both subsets in the master map of locations via the relevant feature maps. This would result in a reduction of activity at the locations containing nontargets comprised of a feature not present in the target thereby allowing a parallel feature search at locations of the remaining subset. Treisman (1988) further radically altered *FIT* by stating that the master map of locations

occurs in very early processing so that the different features are conjoined prior to the processing of the different feature maps and that the attentional spotlight operates on this early master map, not afterwards, as originally proposed.

Other research using the visual search paradigm has shown that under some conditions conjunction search may be parallel, indicating that an attentional spotlight may not be required to bind individual features together.

Before the development of *FIT,* Shiffrin & Schneider (1977) had devised a late selection model based on the differing effects of controlled and automatic processes that they equated with serial and parallel processing respectively. In a series of experiments they used a matching task where one to four letters were displayed and memorised (the memory set) followed by a display showing one to four letters (the display set). For the consistent mapping condition, one set was comprised of consonants and the other numbers. For the varied mapping condition, mixtures of both consonants and numbers were used for both sets. A decision was required as to whether an item from the second set matched an item from the first. They found that the number of items present in either set significantly affected decision speed in the varied mapping condition (indicating serial processing of both the memory and display sets) but not for the consistent mapping condition (reflecting a parallel search). Shiffrin & Schneider (1977) suggested that the automatic processing found for the consistent mapping condition reflected years of practice in distinguishing between letters and numbers. This was tested using two sets of consonants (B to L and Q to Z) for the consistent mapping condition instead of letters and numbers, reversing the mapping after 2100 trials. After the initial 2100 trials, they found performance greatly improved, indicating the growth of automatic processes. However, they also found that the reversal of the mapping condition markedly affected performance, taking almost 1000 trials just to match the performance levels obtained at the very start of the experiment. These findings would suggest that while automatic processing is fast and parallel, it is also inflexible whereas controlled processing is slow and serial but shows a high degree of flexibility (see also LaBerge, 1973; Leber & Egeth, 2006; Rabbitt, 1967). Such studies provided difficulties for *FIT* in that qualitative changes in performance were found after practice.

However, when Treisman & Gelade (1980) tested conjunction searches for colour and shape (letters), they found that although the size of the intercept values of RTs changed over time, the slope values varied very little (experiment one). This, they suggested, indicated no appreciable change from serial to parallel search after 1664

trials. Treisman, Vieira & Hayes (1992) looked at whether extensive practice would result in the formation of an integrated representation in memory and thus to the formation of a new special purpose conjunction detector. They gave participants extensive practice in searching for targets comprised of connected line segments amongst similar non-targets but any benefits of practice found for one task did not generalise to other tasks.

Research using primitive features has also found that multiple items can be processed in a single attentional fixation[3], providing further evidence for a small number of emergent features without the need for extended practice (e.g. Cavanagh & Anstis, 1991; Chen & Zhou, 1997; Grossberg, Mingolla & Ross, 1994; He & Nakayama, 1992; Pashler, 1987a/b; Steinman, 1987; Treisman, 1992; Treisman & Paterson, 1984). For example, Steinman (1987) found near flat conjunction search for stimuli defined by combinations of binocular disparity and orientation, and for binocular disparity and vernier offsets. Similarly, Cavanagh & Anstis (1991) found the same near flat conjunction search for stimuli defined by combinations of colour and motion. Holcombe & Cavanagh (2001) also showed that both colour and orientation and brightness and orientation are bound at very early stages. Similarly, Chen & Zhou (1997) found that abstract topological properties (holes) can be detected in parallel and He & Nakayama (1992) found that preattentive processes can fill in occluded contours.

When Steinman (1987) examined the performance for conjunction search for small line segments in a variety of combinations (e.g. vernier offsets, stereoscopic disparity and line orientation), he found that after 10,000 trials search functions were flat in all conditions. However, he concluded that this qualitative shift in performance was due to participants learning how to segregate displays using one of the target features. Thus, by narrowing the search to items containing one salient feature, pop-out could occur on the corresponding feature map but only after participants became highly familiar with the relevant features (see also Dehane, 1989; Egeth, Virzi & Garbat, 1984; Nakayama, 1990; Treisman, 1988; Zohary & Hochstein, 1989). Indeed, Treisman, (1982) had found similar effects for spatially grouped nontarget items.

Similarly, Nakayama & Silverman (1986b) found featural pop-out in cross-dimensional conjunctions search but indicated that this may be due to segregation (see also Poirier & Frost, 2005). Using a standard visual search paradigm with displays of

[3] An attentional fixation (dwell time) is purported to be analogous to an eye fixation and is the time attention remains fixed at one location. This, it has been suggested, lasts for as little as 40 msec (Wolfe, Cave & Franzel, 1989) or as much as several hundred msec (Ward, Duncan & Shapiro, 1996).

various small coloured items laid out as chessboards, items were presented either in one stereo depth plane or divided between two (near or far in relation to the participant). Near non-target colours were presented in one primary colour and far in another (e.g. red and blue). The target was defined by a conjunction of depth and colour (e.g. near blue). They found that conjunction search was unaffected by display size, implying parallel search. They concluded that for displays segregated into two depth planes, once segregated, the target differed in one salient feature from the non-targets in the same depth plane and hence could be easily discriminated (e.g. a near blue target in a field of near red nontargets). They found the same effects for motion and disparity. Further, the mean RT for the stereo depth and colour trials was less than for stereo depth and motion trials indicating that there was some ordering of difficulty. Thus, they suggested, there is evidence that featural pop-out can occur in cross-dimensional conjunction searches, indicating that all searches for conjunctions of features are efficient and parallel provided that individual features are salient (see also Dehaene, 1989; Duncan & Humphreys, 1989, 1992; McLeod, Driver & Crisp, 1988; Nakayama, 1990; Steinman, 1987; Treisman, 1988; Treisman & Sato, 1990; Wolfe *et al*, 1989; Zohary & Hochstein, 1989).

Pashler, (1987a/b) found that conjunction search for colour and shape was parallel only when displays containing fewer than eight items were used. He concluded that search only became serial and self-terminating when displays contained two or more groups of eight or more items. Other studies have demonstrated that search time can be reduced when nontargets are processed in groups (e.g. Grossberg *et al* 1994; Muller, Humphreys & Donelly, 1994), and grouping processes have been found for as few as two similar items (e.g. Bayliss & Driver, 1992; Mordkoff & Yantis, 1993). However, several studies have shown that pop-out does not occur if uniqueness is not associated with a target (e.g. Jonides & Yantis, 1988; Prinzmetal & Taylor, 2006; Theeuwes, 1990). VanRullen & Koch (2003) found that when attention is focused elsewhere, some conjunction targets (natural scenes and colour-orientation) do not pop-out even when they can be easily discriminated from distractors. Northdurft (2006) found that salience detection and target identification followed different time courses in that targets that popped-out were located faster than they were identified. He also found that when the salience of individual features was increased, the effective set size was reduced and search performance improved. As a result, he argued that both salience and top-down attentional guidance were interactive and complementary processes.

Fast, parallel search has also been found for aspects of the three dimensional (3D) scene that result in a 2D image (Enns & Rensink, 1990a/b). Ramachandran (1988) further found parallel segregation for differences between shape and shading. Therefore, search is unlikely to be parallel without a shading feature also being present to allow for clear segregation. Simple neural networks, trained to respond to gradients of shape from shading were shown by Lehky & Sejnowski (1988) to evolve hidden units (layers of units found between the input and output units). These appear remarkably similar to the specialised cells in area V1 found by Hubel & Wiesel (1960) that while originally assumed to detect bars or gratings may, in fact, be specialised to sense shape from shading. Therefore, not only might convexity and gradients of shading mediate grouping, allowing for parallel search, but the features that are initially coded by the visual system may, in fact, be the surface features of 3D objects. Such research would indicate that the features that determine both grouping and pop-out are not the features of the retinal image but rather the features that specify 3D objects in the real world.

It has also been shown that, under certain conditions, pop-out can occur for within-dimension conjunctions. For example, Wolfe *et al* (1989) found parallel conjunction search for highly discriminable sizes, vertical & horizontal orientation, circle and cross shapes as well as for the colours red and green. Treisman (1991) suggested that such within-dimensional pop-out would only occur for a limited number of dimensional values. Using both search and illusory conjunction tasks she found not only that search appeared to be serial even though both features of the target were objectively different and easily discriminable from the distractors but that a large number of misperceptions occurred. Far more illusory conjunctions were made when within-dimension binding was required than when between-dimension binding was required using primary feature detectors (for example blue and vertical) with a target that was similar to the distractors. Primary (unique) features are features that are not a product of two or more within-dimension features, such as red, blue, green and yellow or vertical and horizontal. Secondary (binary) features are a product of two or more within-dimension features, such as purple that is comprised of red plus blue, or diagonal that is comprised of vertical plus horizontal. She proposed that these results showed that within-dimension features can be divided between primary features that are coarsely bound to their locations and secondary features that are not. However, it should be noted that Buchanan-Smith & Heeley (1993) demonstrated that small

deviations from the vertical (8^o tilt) can be easily detected. D'Zmura (1991) also found fast, parallel search for binary colours. These studies call into question Treisman's (1991) conclusions that pop-out can only result from a limited number of primary features.

Duncan & Humphreys (1989, 1992) also emphasised that differences between feature and conjunction searches do not reflect an underlying distinction between feature and conjunction processing. Rather, the pattern of linearly increasing search times with set size is directly related to the similarity of the target to the non-targets and inversely related to the similarity of the non-targets to each other. They proposed a late selection model comprised of three stages. First, an initial parallel processing stage computes a perceptual description of all stimuli present in the visual field, grouping them according to Gestalt laws. This representation is hierarchical and results in a set of structural units similar to the temporary object files of *FIT*. A second selective stage, which is competitively based, directs attention to a section of the visual input and determines how accurately the selected input matches an *a priori* description of all possible targets and distractors (an attentional template) and is weighted accordingly. In the third stage, the difference in the weight allotted to each individual item and the weight of items in the attentional template is distributed to the other items within a perceptual group (weight linkage) and determines the degree to which individual items compete with others to enter the limited capacity visual STM store. Thus, the spreading suppression along these linkages allows items within a perceptual group to be rejected as nontargets en masse. Therefore, the difficulties in conjunction search occur not only because the target is comprised of a feature from one-half of the distractors that have been grouped together with a feature from the remaining distractors, but because the two groups of distractors are highly dissimilar (see also Roggerveen, Kingston & Enns, 2004).

However, as a result of Duncan & Humphreys' (1989) research, Treisman (1992) suggested that when all other factors have been controlled for, there was still little evidence to support the notion of spreading suppression. The difficulties experienced for conjunction search cannot simply be accounted for by recourse to similarity. Nevertheless, Duncan & Humphreys (1992) did demonstrate that the notion of similarity both of the items within a single search display and with all possible target items must be considered in any account of visual search performance.

Research using the illusory conjunction paradigm has also provided strong evidence to show that search for a complex object can be parallel. Tsal (1989) suggested that such research does not show that attention is a prerequisite for integration because a significant number of unattended features have been shown to be both accurately perceived and bound (e.g. Treisman & Schmidt, 1982). He pointed out that such results would imply that either unattended items were, in fact, attended or that focused attention is not a prerequisite for binding. Certainly, most, if not all such studies have obtained similar findings. Tsal (1989) argued that such results show that individual features can be bound without the need for focused attention.

Moreover, Tsal, Meiran & Lavie (1994) proposed that Treisman & Schmidt's (1982) experiments and many similar ones used a weak manipulation of attention that is not strong enough to produce wholly attended or wholly unattended stimuli. Therefore, such experiments may have produced the location uncertainty that results from spreading, redirecting or shifting attention as well as not giving enough time for the memory trace to decay. To control for any memory influences, Tsal *et al* (1994) used the same stimuli as Treisman & Schmidt (1982) but with coloured flanking digits (experiments one and two) and with three coloured letters only, two on one side of fixation and one on the other (experiments three to five). They tested whether illusory conjunctions could be found when attention was strongly manipulated by correctly pre-cuing the target location. They found that while illusory conjunctions were formed when attention was weakly manipulated, when it was strongly manipulated, true illusory conjunctions were not manifested. They suggested this indicated that illusory conjunctions only occur when attention is weakly manipulated so that no clear distinction can be made between attended and unattended items.

Nevertheless, both Johnston & Pashler (1990) and Donk (1999) maintained that illusory conjunctions result from errors of target-nontarget confusion and not as a result of the incorrect binding of correctly perceived features. For example, a colour conjunction error may occur if the distractor letter was misperceived as the target letter. Prinzmetal (1981) showed that illusory conjunctions occur more frequently when the constituent features of shape are presented within rather than between perceptual groups whether defined by proximity or similarity. Using displays containing two groups of four circles, he found that participants were more likely to report an illusory cross when both features form part of the same group of four circles (a in figure 1.3 below), despite

the presence of an intervening circle, than when a single feature is present in each of the two groups (b in figure 1.3 below):

Figure 1.3: Illusory conjunctions between features of shape taken from Prinzmetal (1981).

Prinzmetal (1981) suggested that the visual system analyses the visual array into perceptually grouped units before individual features are integrated (Kahneman, 1973; Neisser, 1967). Khurana (1998) extended these findings to include complex objects and Prinzmetal & Mills-Wright (1984) to words. Such results indicate that consistent error patterns more accurately reflect the presence of global rather than featural primitives.

Jacobs, Nazir & Heller (1989) investigated the perception of letters in peripheral vision and found that such letter confusion is determined by the dissimilarity in their global features (e.g. width to height ratio) and not to their local features (e.g. orientation of individual letter elements). Therefore, the use of letter stimuli that can be discriminated on the basis of highly dissimilar local features may still result in confusion errors if their global features are similar. However, when Khurana (1998) examined the integration of form and colour, she found that rather than illusory conjunctions being formed when objects were perceptually grouped, it was always colour that was mislocalised not shape, indicating that grouping occurs within but not between dimensions. She proposed that objects are scanned from the edges inwards, so that form constrains the way that colour is integrated in much the same way that global boundaries constrain the computation of feature contours. Thus, colour and form are independent at a global level with form being processed faster than colour (see also Schwartz & Loop, 1982).

Letter confusions can also result from decreasing inter-item distance (Appleman & Mayzner, 1982) and from increasing retinal eccentricity (Bouma, 1970). Bouma (1970) suggested that it is not just adjacent objects that will result in impaired

perception of the target but any number of distractors *crowding*[4] round the target, provided that the distance between each item is equal to, or less than, half the distance between the target and a central fixation point of the target object providing an eccentricity of 0.5. This is known as "Bouma's bound" (see also Toet & Levi, 1992). Similar results have been found for both line segments and grating patches (Andriessen & Bouma, 1976; Wilkinson, Wilson & Ellemberg, 1997) although Andriessen & Bouma (1976) found that for fine discrimination of orientation this reduced to an eccentricity of 0.4 as did Wilkinson *et al* (1997) for contrast and spatial frequency. Chung, Levi & Legge (2001) and Pelli *et al* (2004) also showed that for letter contrast, eccentricity was less than 0.3.

Two explanations have been put forward to account for crowding. The first proposed that feature detection responses involve spatial pooling at a higher level of processing (e.g. Parkes, Lund, Angelucci, Solomon & Morgan, 2001; Wilkinson *et al*, 1997). Therefore, it is not just an adjacent object that can interfere in identification tasks but any number of competing features that crowd the target. The second explanation to account for crowding suggests that inhibitory interactions occur between spatially adjacent mechanisms that are sensitive to similar features (e.g. Bjork & Murray, 1977). However, while recent studies have supported the idea of spatial pooling by showing that crowding does not inhibit detection (Levi, Hariharan & Klein, 2002; Pelli *et al*, 2004), others have found that target pop-out can reduce the crowding effect although this effect varies both with the types of features used and with differences between participants (Felisberti, Solomon & Morgan, 2005; Kooi, Toet, Tripathy & Levi, 1994).

Felisberti *et al* (2005) have further argued that the pop-out effect is not strong enough to account for the reduction in the *crowding* effect found. Põder (2006) also argued that the crowding effect was only apparent for homogenous targets. Provided the target is salient, as the number of distractors within Bouma's bound increases, so the *crowding* effect reduces. He further suggested that the salience of the target must be greater than that of the distractors in order to reduce the crowding effect. Põder (2006) concluded that these findings, rather than resulting from a direct feature-based selection mechanism, are based on the salience of the target location. This suggests that attentional selection results from a combination of multiple mechanisms at different

[4] A term first coined by Stuart & Burian (1962) to account for participants' difficulties in identifying a letter flanked by other letters in peripheral vision.

levels of processing, each with different sized receptive fields (see also Tsotsos, Culhane, Wai, Lai, Davis & Nuflo, 1995; VanRullen, 2003).

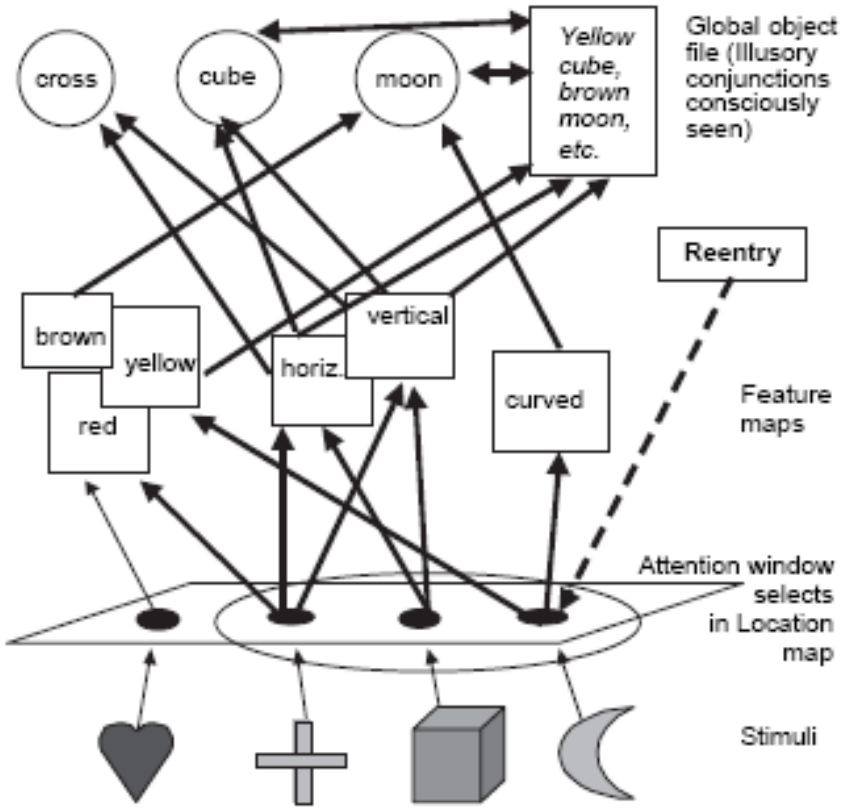

Figure 1.4: Diagram of feature integration theory where attention is spread over three items instead of being focused on one. From Treisman (2006).

That preattentive processes can extract the individual components of more complex objects such as three-dimensional form and topological attributes and complete occluded contours would clearly indicate that feature binding can occur without focused attention. He & Nakayma (1992) proposed that preattentive output comprises not only a set of individual feature maps but a representation of an object's surface. However, rather than attributing such findings to preattentive processing, Treisman (1993) argued they could be accounted for by differentiating between preattention and divided (distributed) attention (see figure 1.4). Thus, preattentive processing can be seen as a stage of early vision in which features are tagged to their location and coded into individual feature maps. Whereas, when attention is distributed across the whole of the visual field, texture segregation, pop-out and the detection of global alignment and shape occur. However, to accurately localise and integrate the features of a single object, attention must still be narrowly focused (see figure 1.5).

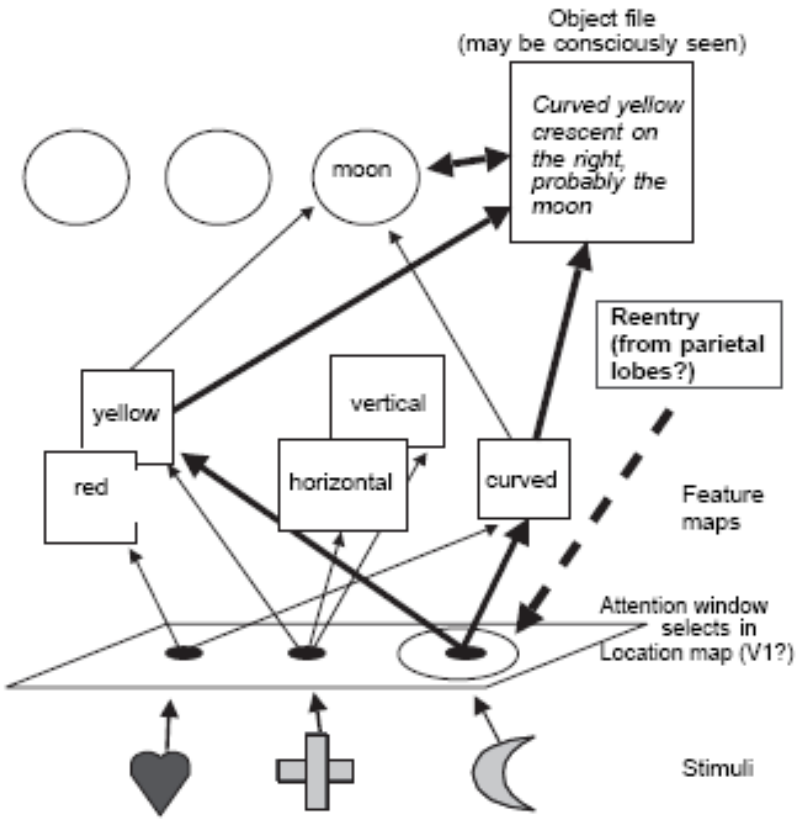

Figure 1.5: Diagram of feature integration theory when attention is focused on one object. Features from the selected location are coded into an object file where they are bound. Non-selected features are excluded from the object file. From Treisman (2006).

It would appear that the independence of featural processing is still very much open to question. Indeed, problems associated with both feature independence and discriminability have beset *FIT*, particularly in relation to the insistence that qualitative differences exist between feature and conjunction search.

1.2.3.2 METHODOLOGICAL PROBLEMS

The use of latency as a measure to distinguish between feature and conjunction search has also been questioned by a number of researchers. The use of latency was first developed by Sternberg (1966), who stated that firstly, the rate of scrutinizing locations was constant (two locations will take twice as long to search as one) and secondly that search is exhaustive (it will not end when a match is found but will continue until all items have been scrutinised). If search was self-terminating, then RT would increase directly in proportion to the number of items processed with a steeper slope resulting from negative responses. As a result, he interpreted STM search in terms of a serial linear relationship, thus rejecting a number of parallel models.

Some researchers have argued that the measure of reaction time by set size proposed by Sternberg (1966) does not adequately discriminate between parallel and serial mechanisms (Atkinson *et al*, 1969; Egeth, 1966; Townsend, 1971; 1972; 1990). For example, serial self-terminating search can be produced by limited capacity parallel models such as those put forward by Kinchla (1974), Ratcliff (1978) and Ward & McClelland (1989). Such limited capacity models propose that all display items are processed in parallel with search terminating when evidence from each location accumulates sufficiently for either one item to cross a 'yes' threshold or for all items to cross the 'no' threshold. The rate of accumulation depends on the amount of parallel resources that are available, with an increase in set size resulting in a corresponding decrease in resources for each item, thus slowing the time to reach threshold. This results in an increase of RT with set size. Indeed, theorems demonstrating equivalence for many serial and parallel models have been developed (Townsend, 1976; Vorberg, 1977).

Nevertheless, although the linear relationship between RT and set size is regarded as reflecting limited capacity rather than being a reliable measure of the distinction between parallel and serial processing, under some circumstances, flat RT slopes can be strong indicators for parallel processing (Egeth, Jonides & Wall, 1972; Townsend & Ashby, 1983). Despite these problems many researchers still persist today in concluding that increasing linear RT functions imply serial processing. More recently, Thornton & Gilden (2007) reanalysed data from twenty-nine relevant visual search studies and found that while the majority of searches are parallel and limited in capacity, a separate and distinguishable number of searches are serial.

Problems have also been identified with the use of accuracy as the dependent measure. Treisman & Schmidt (1982) had stated that illusory conjunction errors are genuine perceptual phenomena caused by attentional overload and so could not be attributable to either response biases or interchanges of verbal labels. Thus, because each feature in a display is coded independently, when attention is diverted or overloaded, two features from different objects in the display may be combined at random to form an illusory conjunction. However, they found it difficult to rule out whether a proportion of illusory bindings also resulted from memory failures or guessing (see also Prinzemetal *et al*, 1986). To determine this, they proposed that in a full report design, subtracting feature error responses (in which either a colour or shape not present in the display was selected and conjoined with a feature present in the

display), from illusory conjunction responses, (when a feature from a non-target item is conjoined with a target feature), would give the number of true feature binding errors. Further, although giving no explanation, they stated that the number of illusory bindings should be 50% higher than the number of feature errors. They consistently found that conjunction errors exceeded feature errors by significantly more than this amount and concluded that provided this was the case, then all illusory conjunction responses could be treated as true feature binding errors. A similar methodology was used by Cohen & Ivry (1989). However, neither Treisman & Schmidt (1982) nor Cohen & Ivry (1989) provided a detailed account of their reasoning.

In contrast, Navon & Erlich (1995) proposed that the number of illusory conjunction errors significantly exceeding feature errors was not an indication of true illusory conjunctions being made. Rather, conjunction errors were merely far more likely to occur by chance than were feature errors. Navon & Erlich (1995) used Treisman & Schmidt's (1982) original single and dual task design, comprising a masked display of two digits flanking three central coloured letters. In one condition, onset of the digits and central coloured letters was simultaneous. In a second condition, this was varied so that digits followed letters. Three types of probe letter appearing after offset of the mask were also added. These comprised either a letter identical to a coloured letter displayed; one that matched a single feature with a second feature not used anywhere in the display; and one combining a feature from one stimulus with that from another in the display. For these, a decision had to be made as to whether the probe matched any of the stimuli. Exposure durations were also varied. While Navon & Erlich (1995) found that conjunction errors were significantly more frequent than feature errors with the number of conjunction errors remaining constant across both single and dual tasks. However, feature errors occurred more frequently in the dual task condition when digits had to be reported first. They argued that these results indicated that illusory conjunctions arise because of post-perceptual factors, contrary to *FIT*'s assertion that they occur at a perceptual-attentional stage of processing prior to any response or decision stage. Indeed, other studies have found that higher order factors do have a direct bearing on performance, although only when familiar stimuli are used (Prinzmetal & Mills-Wright, 1984; Prinzmetal *et al*, 1986; Virzi & Egeth, 1984).

However, Coltheart (1980) suggested that stimulus information is available after its offset but that location information decays faster than information about a feature's identity. Regan (1985) looked at memory for spatial frequency and found that memory

for simple gratings was accurate up to 20 seconds. Similarly, Magnussen, Asplund, Dyrnes & Greenlee (1988) using gratings containing single spatial frequencies of between 5 to 20 cycles deg^{-1} found memory retention over intervals of 30s was almost perfect. Hole (1996) found similar effects for aperiodic stimuli as well. For example, in experiment one, two stimuli were presented sequentially for comparison, both comprised of two spatially separated white dots on a black background presented for 3s. The interval between stimulus presentations (ISI) varied between 40msec and 30sec. While some decay was apparent over time, even at 30s intervals, this decay had only increased by 9%, indicating that the representation of the spatial relationship of the first stimulus shows a high degree of precision when the second stimulus is still physically present. Experiment two looked at effects of interference during the retention period where an irrelevant stimulus had also to be retained. Results showed that an irrelevant similar stimulus had obligatory access to the visual STM store and disrupted retention of the first stimulus. However, Magnussen, Greenlee, Asplund & Dyrnes (1991) suggested that such disruption was unlikely to be caused by distraction or to low level masking because of the interval between presentations. The wide spatial separation (approximately 6.2^0) between dot pairs in Hole's (1996) study would also preclude such a conclusion but he suggested that whether visual noise is averaged with the current representation or overwrites it is unclear. Thus, while STM is able to accurately retain information for a considerable amount of time, it is highly sensitive to interference from subsequent stimuli regardless of whether focused attention is applied or not (see also Toms, Morris & Foley, 1994). Wheeler & Treisman (2002) also suggested that while individual features are stored in parallel independent modules where features from the same dimension compete for limited capacity representation, maintenance of bound objects is dependent on limited attentional resources and any competition for these resources interferes with performance. Such results indicate that spatial information can be held in STM for a considerable amount of time and would indicate that illusory conjunctions are unlikely to occur as a result of a STM failure to hold together individual features previously represented as a bound object due to decay. However, they may occur through subsequent spatial information interfering with the memory trace as indicated by both Magnussen *et al*'s (1991) and Hole's (1996) studies and demonstrated by Navon & Erlich (1995) on trials where onset of the digits varied from onset of the central coloured letters.

Ashby *et al* (1996) also argued that illusory conjunctions cannot be solely due to limitations of visual STM or guessing and proposed that the procedure that had generally been used to date based on feature error rates for colour, shape or both may be overly simplistic and could result in invalid conclusions. They suggested that this might account for whole report tasks where all features present in the display must be reported. However, in a partial report task, where a single target (e.g. a blue T) is to be reported, only two features need to be retained in STM and therefore illusory conjunctions must be true misperceptions. Nevertheless, they did acknowledge that all incorrect responses cannot be taken as true illusory conjunctions. For example, in a display of several coloured letters where there is a target (blue T) plus an adjacent distractor (red O), the response red T may have occurred from an incorrect combination of the distractor colour with the target letter or it may have been that the target letter was perceived but not its colour, or even that the perceived colour was not a colour used in the trial so red was simply a guess. Thus, they suggested that while illusory conjunctions can be seen as real perceptual phenomena, they could also arise as a result of guessing. To resolve the issue, they proposed that an adaptation of the multinomial modelling techniques used by Batchelder & Reifer (1990) could be used which would overcome any problems of partialling out guesses from the data. However, it is difficult to see how multinomial modelling can provide the answer to an empirical issue (whether or not, or how many, illusory conjunctions are guesses).

Nevertheless, Prinzmetal, Henderson & Ivry (1995) tested the three models used by Ashby *et al* (1996) to address the problem of establishing precisely what proportion of illusory conjunctions were the result of guessing. These comprised a "null" model in which it was assumed that all illusory bindings were solely the result of guessing; a "random" binding model which assumes that feature binding errors occur as a result of the unconstrained or "free-floating" physical and/or perceptual relationships of features in the stimulus array (Treisman & Schmidt, 1982); and a "location uncertainty" model which is based on three assumptions. The first is that the constituent features of an object and its identity, while tagged with positional information, are coded independently. The second is that variability exists over trials in the perceived locations of the constituent features of the target object. The third assumption is that this positional information is uncertain in that the colour that appears closest to the target letter is chosen so that an illusory percept is formed when the distractor colour is perceived to be closer to the target letter than the target colour (Cohen & Ivry, 1991).

They rejected both the *null* and *random* models in favour of the *location uncertainty* model.

However, such models assume that the parameters are independent, with information being treated as if it is either completely known or completely unknown with no account being taken of partial information. Prinzmetal, Ivry, Beck & Shimizu (2002) rectified this by the inclusion of partial information parameters and found that where the same colour is not used more than once within a single display, guessing does not occur and suggested that it can be eliminated as a possibility. Indeed, they go so far as to recommend that under such conditions guessing be omitted from any further model. However, no account was taken in respect of blinking or inattention which would also result in either the target letter and/or colour being guessed. Indeed, studies have shown that due to blinking, inattention or not fixating correctly, either or both the target letter and colour must have been guessed (e.g. Bonnel & Prinzmetal, 1998).

It would appear that the methodological problems associated with accuracy indicating that guessing probably resulted from inattention, blinking or a failure to fixate have still not resulted in adequate methods to measure this. However, while the methodological problems associated with latency which highlighted that some conjunction searches could be parallel have resulted in fundamental changes being made to *FIT* it should still be noted that while most searches haves been shown to take place via parallel limited capacity processes, there are some searches that still require serial processing (see Thornton & Gilden, 2007).

1.2.4 ALTERATIONS TO FEATURE INTEGRATION THEORY

Initially, in response to the findings that some conjunction searches could be parallel, Treisman & Sato (1990) tested three hypotheses to determine what conditions permit the early detection of conjunction targets, the results of which led to a radical revision of *FIT*. The first related to the notion that a limited number of special purpose conjunction detectors could form and operate at some early stage of visual processing. The second proposed that grouping processes segregate two types of highly discriminable features of nontargets, allowing search to be restricted to just one of these groups. The third hypothesis suggested that multiple nontarget locations could be suppressed (inhibited) for any features present in the display that were highly dissimilar to the target, again by controlling selection via the master map of locations as in the original *FIT* but now by limiting activation of feature maps much as suggested by Wolfe *et al* (1989) above. Such attentional inhibitory control, rather than building up a single

accurate representation of the visual scene as in the spotlight metaphor, would suppress all but the correct representation. This notion is very similar to Broadbent's (1958) filter model and implies that without any attentional control, all possible conjunctions of the features present within the visual field would be formed rather than none as originally stated. This is consistent with physiological findings that attention narrows the receptive field of cells receiving the target (Moran & Desimone, 1985) although the notion of synchronised oscillations[5] cannot be ruled out (Eckhorn, Bauer, Jordan, Brosch, Kruse, Munk & Reitboeck, 1988).

Across four experiments Treisman & Sato (1990) examined performance for size, colour, motion and orientation in both feature and conjunction search, to determine which of the three hypotheses best fitted the data. Overall, they found that single feature search for all dimensions resulted in flat search functions with relatively fast RTs. They also found that RTs increase linearly with the number of items in the display, indicating that search operates at a featural level and not at a conjunction level of processing. Further, results showed that the greater the number of nontarget types, the greater the difficulty in identifying the target even when the non-targets were highly discriminable from the target. Finally, and crucial in distinguishing between the different hypotheses, they found that while conjunction search functions showed a linear increase with set size, there was a high degree of variability in the slopes of the different functions, indicating not only that conjunction search can be parallel in conditions where features are highly discriminable but also an ordering of difficulty similar to that found by Nakayma & Silverman (1989). Trials where size was one of the features were fastest, followed by colour then motion, with orientation being the slowest.

However, Treisman & Sato (1990) rejected the specialised conjunction detector hypothesis, primarily on the basis that no overall difference in performance was found between those conjunctions where there might be specialised detectors, such as orientation with motion (De Valois, Albrecht & Thorell, 1982) and those where there was not (colour and motion: Hubel & Livingstone, 1987). They also rejected the segregation hypothesis on the basis that no systematic pattern of facilitation by a single salient feature could be found. Rather, there appeared to be an additive effect on conjunction search, suggesting that in displays divided by an equal number of nontarget items, both features independently contribute to search latencies. They suggested that

[5] The temporal binding hypothesis proposes that populations of cells representing primitive features, such as the neurones in the primary visual cortex, respond to different elements in the visual field that are to be bound by synchronising their firing activity to between 40 and 50 Hz.

the additive contribution found indicates not only a process of serial checking of constituent target features against each search item but the registration of several nontarget features. This results in the suppression of activity in the master map of locations. Thus, both sets of nontargets, each with its own relevant feature, contribute to search latencies on every trial (*cf* Treisman, 1988). However, they did point out that while their results do not completely rule out a direct coding hypothesis for some feature conjunctions, they would rather consider alternative strategies that were more compatible with the original *FIT*. Nor do these effects rule out a strategy where, on a given trial, only one feature dimension contributes to the search. To account for the additive effects, they ruled out the notion that all features were checked either individually or in groups, with each item being rejected on the basis of whichever feature differentiates it from the target. Rather, on any given trial, they propose that all participants use the same single feature dimension to control search although this can change from trial to trial. They suggested that this more accurately reflected the inhibition hypothesis that allows for inhibition in multiple feature maps. These conclusions resulted in *FIT* being further revised so that either a salient external event or top-down inhibition from the feature maps can result in a serial scan of the master map of locations.

It can be seen then, that extensive modifications have been made to the theory with the result that the capabilities ascribed to the two stages have been drastically altered. *FIT* now postulates that the retinal image is initially coded by an array of feature detectors, each simultaneously coding one of the many feature values such as "red", "round" or "vertical" from each of the feature dimensions (curvature, tilt, colour, shape, line-ends and movement). This produces a retinotopic map which is topographic in that adjacent feature detectors represent the activity at adjacent image points. The retinotopic map projects, in parallel, to a set of feature maps, each registering a single coded image feature. However, all topographic information is lost during the mapping although some primitive grouping processes (texture segregation and figure-ground grouping) take place. This enables both edges and boundary information to also be coded, allowing the elements within each feature map to combine. While this coding is parallel with unlimited capacity, no cross-referencing between these maps takes place. Nor is there access to the master map of locations. Thus, information is not shared between each of the feature maps. At the preattentive stage, the visual system is only capable of detecting the presence of individual features across the visual field, with both

feature identification and localisation being under attentional control. Three spatially selective mechanisms are now advocated to resolve the binding problem: inhibition of location information from individual feature maps containing unwanted information; selection via spatial attention; and top-down activation of the location containing the currently attended object.

Despite the difference between inhibitory processing of nontarget features and facilitatory processing of target features for conjunction search, *FIT* now closely resembled the guided search model put forward by Wolfe *et al* (1989). Using elements from both the initially modified *FIT* (Treisman & Gormican (1988) and the selective serial model of Hoffman (1978). Wolfe *et al* (1989) proposed a guided search model also based on a *winner-takes-all* (*WTA*) rule (see also Cave & Wolfe, 1990; Wolfe, 1994a). Hoffman's (1978) model suggested that fast, parallel but error-prone processing of a stimulus display provides an overall measure of the similarity between each item and a pre-specified target that, if exceeding a certain value, is serially transferred to an activation map. Items on the map then proceed to the second stage and are serially matched against the target. Contrary to the suggestion that attention can be shifted between stimulus items at the high rates indicated by simple serial models (Colegate, Hoffman & Eriksen, 1973), the second stage is slow, taking on average 100 msec per item. However, as each item is transferred in order of decreasing similarity, a match to the target is likely to be found early thus providing an efficient search (see also Pashler & Badgio, 1987; Remington & Pierce, 1984; Sperling & Reeves, 1980; Tsal, 1983; Weichselgartner & Sperling, 1987).

Thus, the guided search model proposed that parallel processing generates an array of activation values for each feature in the visual field held in a feature map. Each value is a sum of a bottom-up and a top-down component. The bottom-up component provides a measure of the difference between the activation value of a feature at a given location on the feature map and the activation values of the same feature located elsewhere on the map. The top-down component is a measure of the difference between the activation value of a feature at a given location and the target value for that feature dimension. Once all features in the visual field have been processed in this way, the resulting values across all feature dimensions for each location are summed to produce an overall activation map. This provides an evaluation of how likely the stimulus at each location is to be the target. Each item in the activation map is then processed in order of decreasing activation until either a target is found or all items above a certain

level of activation have been processed. Therefore, it is the outcome of the first parallel stage that guides the second stage of serial processing.

However, despite the difference between *FIT* and the *GS* model with regard to inhibitory or facilitatory mechanisms, both agree that: individual features are initially coded independently; individual objects in the visual field compete for attention that occurs via activity in a master map of locations which reflects the current spatial distribution of attention; and that such competition is modulated by grouping processes.

FIT now presents a somewhat complex picture of feature information processing and emphasises that preattention and focused attention are just two extremes of a continuum, with most tasks occurring somewhere between the two. However, at its heart *FIT* retains the very clear distinction between featural detection and featural binding. Without attention and when all strategies have been controlled for, it is claimed that no location information is available for processing and features will be free-floating in relation to one another. With attention, uncertainty about a target's location depends on the width of the attentional window. The smaller it is, the more accurately features will be localised and bound (Treisman, 1993).

Although the role of location in feature binding forms a fundamental part of *FIT* and similar space-based theories, the majority of research investigating location coding have used only categorical measures. Indeed, it was on such imprecise measures that *FIT* was based. The remainder of this literature focuses on these then some more recent research using precise measures of location coding in an effort to establish precisely what location information is made available at different attentional levels.

1.2.5 MEASURES OF LOCATION

The notion that individual features can be identified but not located when focused attention is prevented or diverted was mostly based on research investigating the effects of attention on detection and identification. However, other researchers have questioned the parallel/serial dichotomy in studies dissociating feature identification and location. For example, Bundesen (1991) argued that studies supporting the independence of featural processing could also support the notion that selection for location is no different than that for shape and colour, as long as it is assumed that location information is processed very quickly (see Sagi & Julesz, 1985a/b, below). The view that stimulus location is not uniquely involved in the selection process and is, in principle, no different from other stimulus dimensions such as colour or shape was proposed by Broadbent (1958). He suggested that selective processing is facilitatory in

that relevant information from any physical attribute is channelled for further processing. It has also been suggested that internal structures simply respond selectively to relevant features (e.g. Baylis & Driver, 1992; Duncan, 1984; Harms & Bundensen, 1983; LaBerge, 1975).

Johnston & Pashler (1990; 1991) took issue both with some early studies (Baron, 1973; Krumhansl & Thomas, 1976; Logan 1975) as well as Treisman & Gelade's (1980) findings on the grounds that these studies were susceptible to a binding failure between identity and location because the target can be detected using features present in the display but not present in the target. They cite as an example a target letter (C or G) that is surrounded by a field of black squares. If identification of the target letter is near chance but locating it is very high, this might be taken to indicate dissociation between identity and location. However, it might well have been achieved via gross luminance differences between target and distractors, thus revealing nothing about the binding of the two.

Sagi & Julesz (1985a/b) had already identified this problem and attempted to resolve it. They used briefly presented and masked displays containing either horizontal or vertical bars as targets with diagonal bar distractors and asked participants to either report the number of targets or report whether or not all targets were the same. While they found little effect of display size in the counting task, a large effect was shown for the discrimination task. They argued that while detection and localisation are processed preattentively, identification requires attentional processes. Sagi & Julesz (1985b) proposed a model where, at the preattentive stage, targets are detected via the distance between features resulting in a difference signal that automatically attracts attention to its location. This can be computed in parallel when the distance between adjacent features is relatively small and those discontinuities can be localised. Only then can target identification occur. They stated that discontinuities arising from the comparison of feature modules for neighbouring items are topographic. Thus, in direct contrast to *FIT*, the preattentive system can signal where a target object is without knowing what it is, other than it is different from other items in the display.

Further evidence for this view comes from studies indicating that search performance may improve with increased numbers of nontargets (Sagi, 1990; Sagi & Julesz, 1987). This would suggest that a larger display size meant that items were placed closer together and may have increased the speed with which adjacent items are compared. Atkinson & Braddick (1989) investigated this further using similar displays

to that of Sagi & Julesz (1985a/b). Three tasks were of particular relevance: the *what* task, in which an individual feature was to be identified; the *coarse where* task, where it had to be decided whether the target was in the upper or lower half of the screen; and the *fine where* task, in which it had to be decided from a choice of four possible locations, what position the target occupied. They found that the *coarse where* task produced the shortest RTs while both the *what* task and the *fine where* task produced RT's that were longer. They concluded that while coarse (categorical) localisation of featural information can be recovered before identity becomes available, this is not the case for more exact (co-ordinate) location information.

Johnston & Pashler (1990) also suggested that visual search experiments could suffer from a "location reporting problem". While both the identity and location of a target feature may have been correctly encoded, interference from a mask that uses a different geometric layout from that of the stimulus might result in difficulties in reporting the target's location. To overcome this, participants may have to encode not only the actual position of the target feature but its spatial relationship to other items in the stimulus array. To avoid the problem, Johnston & Pashler (1990) used the same disjunctive feature (colour and shape) search paradigm as Treisman & Gelade (1980) but they redesigned the stimulus displays to show the outline of a square, with each corner and side midpoints containing a letter to provide more discriminable locations.

They also used heterogeneous backgrounds (nontargets) to enable the target to pop-out. To further aid accurate location reports, both pre-stimulus and post-stimulus masks contained a multicoloured character (pink, blue and orange) in each possible target position to provide a general coordinate system to facilitate location reports. To resolve any problems associated with guessing arising from an inequality in the salience of individual target features, pilot studies were conducted to equalize the levels of difficulty in identifying the separate features. In the main experiment, trials where no target was present were included to provide guessing rates for the different features. They found that while both location and identity were correctly reported on most trials, on 10% of trials, target identity was correctly reported but not its location. The very weak evidence for identification without localization, they suggested, indicated that tight binding of identity and location generally occurred preattentively, apparently refuting *FIT*'s claim that features were free-floating in nature. However, although locations of the targets were more easily detected, Johnston & Pashler (1990) counted location as correct if the target was placed in the same half of the display (left or right).

This could be seen as a very imprecise measure and could result in a high number of correct reports if attention was focused in advance on one side of the display.

Figure 1.6: Diagram of example stimuli (not to scale) used by Johnston & Pashler (1990).

Green (1991), on closer examination of earlier studies, found that most equated detection with localisation and did not measure them separately. Nor was the precise role of attention directly addressed. This, however, did not prevent many researchers from concluding that integration is a two-stage process. In an effort to rectify these problems, Green (1992) measured both detection with localisation and detection versus identification. To avoid the artefact highlighted by Johnston & Pashler (1990), where the target may be localised using features not present in the target but present elsewhere in the display, he used Gabor targets tilted at 45^{o} either left or right and vertical distractors, with homogeneous distractors on a background of the same mean luminance (see figure 1.7).

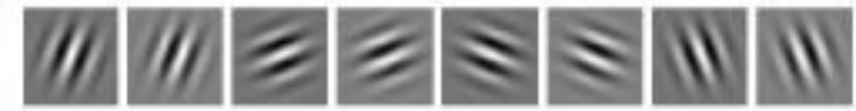

Figure 1.7: Examples of tilted Gabor targets. These are comprised of areas of Gaussian modulated sine wave gratings that have been blurred at the edges and displayed on a background of the same mean luminance.

Each display consisted of 2 to 32 distractors arranged in three concentric circles (detection versus identification) or in a square formation (detection versus localisation), visible for approximately 17 msec. Next, a uniform grey field of the same luminance as the stimulus but of varying durations was presented. This was followed by a mask comprised of both possible targets and distractors, visible for approximately 84 msec. After 1 sec, the sequence (interval) was repeated but with the distractor positions changed. A target replaced one of the distractors in either the first or the second cycle. Experiment one measured detection (decisions about whether the target was present in the first or second sequence) and identification (decisions about the target's orientation). Experiment two placed the stimuli in a square rather than a circle, with items equally distributed between left and right of centre, and measured detection versus localisation

(left or right of the visual field). Results showed no difference in accuracy between detection, localisation and identification. However, while it was found that detection improved with increased numbers of items, no deterioration in performance was found for increases of up to 8 items, as reported by Sagi & Julesz (1987) and others (e.g. Folk & Egeth, 1989). Green (1992) suggested that if a target can be detected, it can be both localised and identified and focal attention is not required to integrate features. He argued for a model in which, rather than there being a master map of locations or a central attentional control process, individual feature maps containing topographic information are directly connected to each other. Thus, feature detection and integration occur in a single operation with control being distributed with focal attention having no role to play in the binding of features. However, as only one target was used on each trial, the issue of parallel versus serial processing was not adequately addressed. Further, as with Johnston & Pashler's (1990) study, Green (1992) did acknowledge that localisation judgements were imprecise and may have resulted in a higher number of accurate responses than would be the case if more accurate location responses had been required.

Saarinen (1996) suggested that because the level of difficulty of both identification and localisation performance can be independently manipulated, comparison depends on both having equal difficulty. For example, Atkinson & Braddick (1989) found that when only coarse location information was required, location accuracy was greater than identification accuracy. However, when fine location information was needed, both localisation and identification were equally accurate. While they argued that their results indicated that two qualitatively different mechanisms underlie coarse and fine location judgements, Saarinen (1996) proposed that it was because only the localisation task was manipulated. Thus, direct performance comparisons cannot resolve the issue of priority between identification and localisation.

To show this, Saarinen (1996) manipulated a location task to determine whether location processes are dependent on identification processes, the reverse, or if both processes are independent of each other. In both experiment one (easy location task) and 2 (difficult location task) the visual field was divided into four quadrants. The stimulus consisted of a target comprised of an oblique black line segment orientated at either 45^{o} or 135^{o}, randomly presented in one of the four locations together with either1, 5, 17 or 39 vertical distractors. The identification task for both experiments was to

report whether the target was orientated at 45^{o} or 135^{o}. For experiment one, the location task was to determine whether the target was in the left or right visual field and for experiment two, whether it was in the upper or lower visual field. In experiment one, responses were made using the left hand for left judgements and the right hand for right. In experiment two, participants were required to use their left hand to indicate the up location and their right hand for the down location. RTs indicated that while location responses were faster than identification responses in experiment one, this was reversed in experiment two. To resolve any perceptual difficulties (left versus right and up versus down) and neutralise any response compatibility effects between experiments, experiment three replicated experiment one but with the manner of response reversed so that left location responses now required use of the right hand and vice-versa. This resulted in no difference between identification and location performance. Saarinen (1996) argued that these results indicated that valid comparisons of performance between identification and location depend on both tasks being of equal difficulty.

However, early work by Sperling (1960, 1963), Estes & Taylor (1964) and Neisser (1967) into iconic memory had already found that at very early stages of processing, features are encoded together with their locations. For example, Sperling (1960) presented a 50 msec stimulus comprised of three rows of four letters followed by a blank white screen. Participants were only able to report 4 or 5 of the 12 letters. To determine whether this was because they had not seen the remaining letters or whether they had been forgotten, they were instructed to report just one of three rows, dependent on a tone heard after stimulus presentation. Participants were now able to report approximately three of the four letters in the cued row implying that about nine letters had been processed in all. These results were interpreted as indicating that letters were being read from a rapidly decaying visual memory trace. To test this, Sperling (1963) varied the duration of the blank white field and found that the advantage of cueing a single row of letters declined until at 500 msec, it disappeared. These results are consistent with the idea of 500 msec persistence in the visual trace. By varying brightness of the blank screen both before and after the stimulus, he found that persistence of the short-term visual trace could be varied considerably. It appeared that the brighter the flash of light presented after stimulus offset, the worse the performance. Sperling suggested that these results indicated that the spatial locations of letters are being transferred from a fragile peripheral store into a more durable sensory one (termed iconic by Neisser, 1967).

Subsequent experiments have shown that other cues such as colour (e.g. Von Wright, 1968), shape and size (Turvey & Kravetz, 1970) facilitate selective processing. Similar results have been obtained for orientation (Palmer *et al*, 1993) and line length (Morgan *et al*, 1998) using psychophysical thresholds. These results, because of the very short stimulus onset asynchrony (SOA) that precludes any saccadic eye movement, indicate that each of these features must have been coded along with their location. Both Shih & Sperling (1996) and Cave & Zimmerman (1997) suggested that such feature driven location selection highlighted the importance of location in selection and indicated that adjacent distractors interfered with target identification.

Cohen & Ivry (1989) examined Sperling's (1960, 1963) claim that locations were tagged to individual features. In a dual task study using an illusory conjunction paradigm, they not only found that the number of illusory conjunctions made were significantly higher when two features were adjacent than when they were distant but that conjunction search slopes indicated parallel processing provided objects were separated by more than 0.78^{o} of visual angle. They suggested that the spatial coding of features is not dependent on attention but is available preattentively. To recover a feature conjunction, the common spatial location must be accessed in iconic memory. Thus, contrary to Treisman & Gelade's (1980) proposal and in direct contrast to Treisman & Schmidt's (1982) findings that distance had little, if any, effect on the likelihood of an illusory conjunction forming, Cohen & Ivry's (1989) data suggest that features are initially perceived with some coarse information about their location. However, this information is not detailed enough to prevent illusory conjunctions being made between adjacent objects (see also Newby & Rock, 2001; Prinzmetal, Amri, Allen & Edwards, 1998; Tsal *et al*, 1995; Tsal & Shalev, 1996, Valdes, 1993).

Cohen & Ivry (1991) attempted to determine whether coarse coding occurred both within a single dimension (colour) and between dimensions (colour and shape). For conjunction targets, they not only found that search slowed linearly with the number of items in the display but also that it was significantly slower for objects placed close together. However, no such effects were found for single dimension targets. As a result, they proposed a dual component model for feature integration. An initial fast mechanism integrates individual features on the basis of coarse location information that occurs in parallel with feature registration. A second, slower mechanism operates when objects are tightly grouped. Several other studies have also found that illusory conjunctions are more likely to occur when objects are spatially adjacent (e.g. Chung *et*

al, 2001; Cohen & Shoup, 2000, Hazeltine *et al*, 1997; Keele *et al*, 1988; Prinzmetal & Mills-Wright, 1984; Rapp, 1992).

However, Treisman (1998) did point out that it is difficult to distinguish between the coarse coding of location and the zooming in of the spotlight of attention to define a general area of the visual field. Prinzmetal, Nwachuku, Boanski, Blumenfeld & Shimizu (1997) investigated this using both distributed and focused attention conditions to determine the effects of attention on the perceived location of a shape (dot). They consistently found that focused attention reduced the variance of location responses. Similar results have been obtained for colour, orientation, line length, spatial frequency and contrast (Prinzmetal *et al*, 1998). Several psychophysical studies that examined the influence of stimulus exposure duration on visual performance have also found similar results. For example, form discrimination (Burr & Morgan, 1997), stereo acuity (Harwerth, Fredenburg & Smith, 2003), and contrast sensitivity for moving patterns (Burr & Santoro, 2001) were all found to improve with exposure duration. However, while such research demonstrates a significant improvement in featural detection when attention is focused on the relevant location, indicating that detection is facilitated by focused attention, it does not adequately distinguish between distributed attention and preattention.

Further support for the view that coarse location judgements can occur without the need for focused attention comes from studies using exogenous cueing to direct attention (see Cave & Bishot, 1999 for a review). For example, Jonides (1981) used displays that consisted of a target letter (L or R) that appeared in any one of eight locations on the circumference of an imaginary circle approximately 7^{o} of visual angle in radius. Two types of arrowhead precue were given. A central cue was placed at fixation and pointed in the direction of either a target or a distractor. This was over 3^{o} of visual angle away from the indicated location. The second was a peripheral precue positioned immediately adjacent to either the target or a distractor location. Observers were required to identify the target letter using a left button to indicate an L or a right button to indicate an R. Jonides (1981) asserted that while the central cue required some form of interpretation and an effortful redistribution of attention to the target location, the peripheral cue automatically captured attention.

Other studies, using non-predictive peripheral cues such as luminance changes that provide no information about the impending target have also been shown to automatically attract covert attention (e.g. Posner *et al*, 1980). However, while such a

facilitatory effect is apparent at short SOAs, when SOAs are lengthened, an inhibitory effect is found (IOR or inhibition of return) where each item or location is examined only once (see Klein & Dukewich, 2006 for a review). However, when Pratt & Abrams (1995) cued two items, they found IOR only for the most recent one. Tassinari, Aglioto, Chelazzi, Peru & Berlucchi (1994) found evidence that facilitatory and inhibitory effects, while additive, are independent processes. Prinzmetal, McCool & Park (2005) also proposed that voluntary and involuntary attention affect different processes following selection. They found that while both informative and non-informative cues affected RT performance (controlling endogenous and exogenous attention respectively), only informative cues affected accuracy performance. They suggested that although the perceptual representation of an object is enhanced by voluntary attention, the same perceptual representation is not affected by involuntary attention.

It has also been shown that endogenous attention follows a cue rather than remaining tied to an object (Gibson & Egeth, 1994; Tipper *et al*, 1994). For example, Tipper, Weaver, Jerreat & Burak (1994) compared attentional orienting to both cued and non-cued objects when the cued object was displayed at a different location. Results indicated that the inhibitory mechanism (IOR) followed the cued object to its new location but may have resulted in a frame of reference being recorded for objects so that attentional orienting operates on relative rather than absolute locations and not on the objects themselves. Evidence for the latter conclusion was provided by Baylis & Driver (1993) who suggested that locations are coded hierarchically. Each feature is coded in relation to the object in which they form a part. Therefore, while reporting two features from the same object will require one frame of reference, reporting features from two different objects will require the relative positions of two frames of reference.

Schendel, Robertson & Treisman (2001) further examined facilitatory and inhibitory effects on both object and location based mechanisms in static displays where the shape of the object changed and not the initial object's position. While location cuing effects were found showing facilitation at short SOAs and inhibitory effects at long SOAs, when object cues were used, facilitation effects were found for long SOAs with no object based IOR. These results are comparable to the findings of Ro & Rafal (1999) for dynamic displays and indicate that endogenous attention can also be automatically captured by a salient shape change. Further analysis revealed that while object cueing strongly affected targets at cued locations, it had little effect on targets at

non-cued locations. Schendel *et al* (2001) concluded that their results strongly indicate that object based orienting is contingent upon covert attention first being captured by that object's location.

Baldassi & Burr (2000) studied effects of attention on visual resolution and found that distractors tilted in the same direction as the target facilitated identification and hindered location responses whereas targets tilted in the opposite direction had the opposite effect. They suggested that both feature identification and location were processed in parallel, although orientation was integrated prior to location. Their results also supported the notion that identification is dependent on the perceptual summation of orientation signals by a later integration stage rather than on global integration for a specified region of space.

Such research casts doubt on Treisman & Schmidt's (1982) proposal that individual features can be identified but not located so that individual features are free-floating in relation to each other when focused attention is prevented or diverted. However, there is some evidence to suggest that individual features are bound to coarsely defined locations before the focus of attention is applied. Thus, while Treisman (1993) still maintained that identification could occur without localisation, several studies have shown that this process is reversed, with identification processes being conditioned upon location processes (Donk & Meinecke, 2001; Sagi & Julesz 1985b). Others have proposed that while coarse location coding occurs in parallel, fine location coding remains serial (e.g. Atkinson & Braddick, 1989; Cohen & Ivry, 1989). However, as in *FIT*, all still maintain a dichotomy between parallel and serial processing and those studies that had researched the effects of attention on location coding, all used very imprecise or coarse measures of position where only the categorical relations between objects, such as above/below or left/right are required. None had used a direct or fine measure of location, where either the absolute position of an object or the Euclidian distance between objects was measured (see Kosslyn, 1987). Nevertheless, this did not prevent very definite statements being made by Treisman and colleagues and many other researchers about the effects of attention on location processing.

Indeed, in direct opposition to *FIT*, researchers using exogenous cueing to direct attention have concluded that stimuli can be accurately localised without focused attention. If a cue can automatically attract attention to an item's location then the cue must have been localised before attention has been focused (e.g. Jonides, 1981; Sagi &

Julesz, 1985a/b). Midway between these two extremes is the notion that while some coarse localisation can occur preattentively, fine location judgements require focused attention (Cohen & Ivry, 1989, 1991; Newby & Rock, 2001; Tsal, Meiran & Lamy, 1995; Tsal & Shalev, 1996). Therefore, to clarify the distinction made by Treisman (1993) between preattentive, distributed and focused attention and to determine whether coarse localisation can occur preattentively or requires at least some distributed attention, the direct effects of attention on location coding need to be examined.

The first study to use a direct measure of location to investigate the effects of attention on location coding was conducted by Tsal & Meiran (1993). They used a single stimulus that consisted of a briefly presented letter precued in one of three regions of the visual field. Results showed a significantly smaller spread of localisation responses on validly cued trials than on non-valid trials, indicating that attention does indeed improve location perception. Similar findings but using a dual task (distributed attention) paradigm were reported by Prinzmetal *et al* (1998). They found that localisation accuracy was reduced when attention was allocated away from the localisation task. Both sets of results, while showing that attention significantly improves localisation, also intimated that even in the distributed attention conditions, coarse localisation may occur. However, because neither study ensured that stimuli were completely unattended in distributed attention conditions, clear support for the preattentive coarse localisation view could not be provided. Nor could Tsal & Meiran (1993) rule out that localisation was not facilitated by the use of a circle surrounding the target. Further, in the study by Prinzmetal *et al* (1998), spatial uncertainty was effectively eliminated as all target dots were peripherally displayed at exactly the same distance from fixation.

These problems were rectified by Tsal & Baraket (2005). Using precueing techniques, they confirmed the finding that location accuracy increased with attention. For example, in experiment one, they included both a totally valid cue to maximise attention in the focused attention condition and a totally invalid cue to minimise attention in the distributed attention condition. In experiment two an identification task was additionally used to determine whether reduced precision in location responses would result from limiting attentional resources. While attention consistently reduced the spread of location responses around the stimulus location, even when items are minimally attended coarse localisation occurs and responses are not random. Thus, even with focused attention, a consistent bias of 50% of the target width was apparent

and this increased to 100% when attention was widely distributed to 4^{o} of visual angle. Further, a greater dispersion along the radial than the tangential axis indicated that the asymmetrical spread of location responses are not confined to a horizontal axis but instead relates to all peripheral stimuli. They concluded that the representation of location is comprised of two components, both being required to specify the location of peripheral stimuli. The first component specifies reasonably precisely the radial angle of the peripheral location relative to the centre and the second imprecisely specifies the distance of the peripheral location from the centre. Adam, Ketelaars & Hoek (1993, 1995) found that regardless of exposure duration of the stimulus, localisation accuracy increased when attention was followed by a saccadic eye movement compared to when it was not.

Prinzmetal (2005) found similar results for displays of two dots using an attentional paradigm. However, despite this bias, he went on to suggest that the perceived target location still formed a normal distribution over trials and was neither skewed towards the second object nor in the opposite direction. Morgan, Hole & Glennerster (1990) also with focused attention but with an ISI of 2 seconds, found that while the distance between two foveally presented squares of the same colour can be accurately reported, when each is embedded within a cluster of squares comprised of a different colour, a bias of approximately 10% towards the centre of each cluster was observed. This indicates that the position of the target is strongly influenced by the position of the entire cluster within which it is embedded.

Studies measuring actual locations in visual STM have found that the remembered locations of objects are also subject to distortions such as foveal bias, where both stationary and moving objects that are presented in the retinal periphery tend to be mislocalised towards the fovea (e.g. Mateeff & Gourevich, 1983; O'Regan, 1984). Foveal bias has also been shown to occur regardless of whether or not a fixation point or other salient object is present (Kerzel, 2002, van der Heijden, van der Geest, de Leeuw, Krikke & Musseler, 1999). Werner & Diedrichsen (2002) directly measured the time course of spatial memory distortions and found that even with delays as short as 50 msec, foveal bias was evident and increased as the delay increased (see also Sheth & Shimojo, 2001).

The remembered location of an object can also be displaced from their actual position towards other salient elements present in the display for both moving objects (e.g. Hubbbard, 1995) and stationary objects when briefly presented (e.g. Kerzel, 2002).

For example, when a dot was presented inside a circle, location responses showed a bias towards the periphery of the circle (Huttenlocher, Hedges & Duncan, 1991; Laeng, Peters & McCabe, 1998) or towards the centre of the quadrant that contained the target dot (Huttenlocher *et al*, 1991; Laeng *et al*, 1998). Such bias has also been shown to increase with distance between the two objects (Hubbard & Ruppel, 2000); when the target is offset from either the horizontal or vertical axis (Hubbard, 1995) and when the second object was not visible at the time of judgement (Hubbard & Ruppel, 2000). They suggested that such results indicate that spatial averaging, while present in perception, increases in memory. However, Werner & Diedrichsen (2002) found biased location responses towards a second object except when both objects were very close to each other, in which case the bias was in the opposite direction. They suggested that while there is evidence of an enduring spatial memory representation that encodes categorical information, the early onset of spatial memory distortions is indicative of an almost immediate decay of coordinate information.

Adam, Ketelaars, Kingma & Hoek, (1993) found that coordinate localisation is reduced when saccadic eye movements are prevented (see also Uddin, Ninose,& Nakamizo, 2004). This would indicate that while an exocentric frame of reference is dominant with short retention intervals in saccadic localisation, an egocentric frame of reference is dominant when the retention interval is prolonged. Therefore, rather than the averaging the distance between the target and fixation point (or other salient object) as suggested by Sheth & Shimojo (2001), the representation of space in memory is reorganised around the focused position (egocentrically reconstructed).

Hazeltine *et al* (1997), using an illusory conjunction paradigm with a direct measure of location examined whether the perceived location of an illusory conjunction would be a spatial average of the two contributing features. They found that the perceived location, over trials, formed a normal distribution over the midpoint between the target and the adjacent distractor. They suggested that each constituent feature contributes to the perceived location of an illusory object. Their results would also indicate that letter confusion was not the cause of any illusory conjunctions made as suggested by Donk (1999). Had this been the case, then it would be expected that location judgements would have clustered around the distractor letter.

This finding was further investigated by Prinzmetal (2005) using simple *spatial averaging* (*SA*) and *winner-takes-all* (*WTA*) rules in an effort to determine whether the visual system averages the locations from each position above a certain threshold

thereby minimising errors in location judgements (*SA*) or whether the location with the highest activation is selected thereby maximising the probability of precisely localising objects (*WTA*). The stimulus consisted of a grey dot which was presented on an imaginary circle (diameter either 2.39^{o} or 4.58^{o}) for either approximately 67 msec or 500 msec with a black fixation dot visible throughout the duration of each trial. Three participants completed a total of 8000 trials over eight days. Results indicated a bias towards fixation for two of the three participants with a greater variance in the far condition and with the short duration. Prinzmetal (2005) suggested that because the resulting data showed a cumulative normal distribution, it therefore fit better with the SA model.

In direct contrast to the conclusion that integration occurs via the averaging of location information from all contributing features that go to make up an object, Tsal & Baraket (2005) proposed a *WTA* rule to account for the effects of attention. Tsal & Baraket (2005) proposed that binding occurs via one of several overlapping attentional receptive fields which are distributed across the visual field. These provide only minimal spatial resolution. It is by increasing attentional resources that facilitates the computations needed to provide increasing localisation precision. Therefore, while coarse spatial information is provided by attentional receptive field that shows the greatest activation, fine spatial information is obtained by integrating the outputs of each attentional receptive field that has detected the object and computing their relative activation (see also Tsal & Lavie, 1988; Tsal, Meiran & Lamy, 1995; Tsal & Shalev, 1996).

The vast majority of research using direct measures of location would indicate both that attention does indeed improve location coding and that individual objects are strongly influenced by other objects held within the attentional window. Thus, when attention is distributed across a number of objects, only categorical (coarse) location information is available for processing as evidenced by the bias towards either the fovea or other salient object. Although somewhat imprecise coordinate information is available with focused attention, accurate coordinate information only becomes available in focused attention with a saccade. However, even with saccadic localisation, long delays will still bias localisation indicating that coordinate information decays early in the processing cycle. Nevertheless, it would appear to be extremely difficult to distinguish between the *spatial averaging* rule of Ashby *et al* (1996) and the bias that results from Tsal & Baraket's (2005) model.

It can be seen that problems remain when trying to establish the precise way in which the visual system combines individual features. However, by using distributed attention and the illusory conjunction paradigm, a clearer understanding of the process of feature binding should be gained not only by being able to attribute location responses to individual features but by looking at those illusory percepts that are formed from items that are not adjacent to the target as well as to those that are. Therefore, by further examining which of the three rules (random, unitary and aggregate) best describes the source of the location information that contributes to an illusory percept and taking into consideration the problems noted above, it is hoped that a clearer understanding can be gained of the process by which individual features are bound together to form a coherent object.

CHAPTER 2: THE PERCEIVED LOCATION OF ILLUSORY CONJUNCTIONS

2.1 EXPERIMENT 1

2.1.1 INTRODUCTION

Most researchers agree that spatial location has a special role to play in the process of integrating individually encoded features into unified objects rather than being just another feature such as orientation or size, (e.g. Arnold, *et al*, 2001; Baldassi & Burr, 2000; Bedell *et al*, 2003; Broadbent & Broadbent, 1986; Enns, 2002; Fryklund, 1975; Herzog & Koch, 2001; Nijhawan, 1997; Nissen, 1985; Snyder, 1972; Tsal & Lavie, 1988, 1993; Tsal & Lamy. 2000; Zeki, 2001). However, there is less agreement on the precise nature of this role.

For example, *FIT* (e.g. Treisman, 1993, 1998) maintains that an attentional window, which acts much like a spotlight or zoom lens on a camera moving through space, focuses on one particular region of the visual field. When moving, the attentional window can be narrowed to encompass a single object, widen to contain a group of similar objects or expand still further to include all objects within the visual field. Treisman (2006) suggests that the accuracy with which an object can be located depends on the size of the attentional window and the number of objects held within its beam. If attention has been narrowly focused, a single object file is opened that encompasses all features relating to the object and also provides access to the global properties of shape as well as the boundaries and relationships between individual elements. However, if attention has been deployed in a distributed manner, no access to coordinate information in the master map of locations is available results in only coarse (categorical) information as to the features' locations being available. This can result in an illusory conjunction being formed between any of the features held within the attentional window. Thus, when attention is divided across two or more objects, individual features may migrate from these different locations and bind to form an illusory conjunction which will be perceived to be located at any position within the attentional window. It is not until focused attention selects an area of the location map, inhibiting unattended items that the locations and the features within the attended area are linked and correct binding takes place.

Two other models have been put forward. The first, like *FIT*, also advocates a *winner-takes-all* (*WTA*) integration rule. Tsal & Baraket (2005) proposed that binding

occurs via one of several overlapping attentional receptive fields which are distributed across the visual field which provide only coarse spatial resolution. Increasing attentional resources facilitates the computations required to make available increasing localisation precision. Therefore, while coarse spatial information is provided by the most highly activated attentional receptive field, fine spatial information is obtained by integrating the outputs of each attentional receptive field that has detected the object and computing their relative activation (see also Tsal & Lavie, 1988; Tsal, Meiran & Lamy, 1995; Tsal & Shalev, 1996).

The second such model proposed that the effects of attention do not require a spotlight of attention in order to integrate information and was put forward was by Hazeltine *et al* (1997). They suggested that the effects of attention could be better explained by an *aggregate* model which used the *spatial averaging* rule developed by Ashby *et al* (1996). This model proposes that the retinal image is first coded by an array of feature detectors, each attuned to and concurrently coding one of a number of feature values. If a critical feature falls within the receptive field associated with a particular feature detector, the detector fires with some probability. However, because noise is present during processing, a possibility exists that a feature detector may either fire when no feature is present in the receptive field or not fire when a feature is present. Thus, while individual features are initially encoded with some location information there will be no exact concordance between a feature and its location, rendering the location uncertain. Integration occurs through the spatial averaging of the uncertain locations signalled by the firing of several feature detectors. However, while two features from the same object will generally be perceived to be closest to each other and therefore part of the same object, on occasion, due to the uncertainty of the location information, a feature of the same dimension from an adjacent object may be perceived to be closer to the first object than that first object's own feature, resulting in an illusory conjunction being formed. This is regardless of the number of items present in the attentional window (Cohen & Ivry, 1989; Prinzmetal & Keysar, 1989). The real or illusory object will be perceived in a location that is the spatial average of both contributing features, thus eliminating the need for attentional selection.

Therefore, the three models vary in the contribution that the location information from each individual feature makes to the location of an integrated object. While *FIT* proposes that because each individual feature's location information is not accessible until attention is focused, the amount of location information relating to an individual feature

depends on the size of the attentional window. Therefore, the position of an individual feature could be perceived to be anywhere within the attentional window. Tsal & Baraket's (2005) model however, suggests that it is the location information from a single feature that provides the location information. Finally, while the *aggregate* model also proposes that attention is not required to bind individual features together into a coherent whole, but suggests that it is a *spatial average* of the location information from all contributing features that determines the perceived location of a bound object.

One way to determine which of the models best describes the process of integration is by using the illusory conjunction paradigm because features are combined from neighbouring objects. Hazeltine *et al*, (1997) used this to test what contribution individual features make to the perceived location of an illusory object. They suggested that if *FIT*'s *random* rule was correct and a feature from any item within the attentional window could be combined with the target to form an illusory percept, then over trials, a rectangular distribution of location information between all items in the stimulus array would be apparent. If the second *WTA* model's *unitary* rule was correct and a single feature provides the location information (Snyder, 1972; Tsal & Lavie, 1988), they suggested that this would result in a binomial distribution over trials, half centred round the target shape and half centred round the distractor colour. If, however, a normal distribution centred round the midpoint between the target and distractor was apparent over trials, then the *spatial averaging* rule of the *aggregate* model was supported (Ashby *et al*, 1996; Hazeltine *et al*, (1997).

Hazeltine *et al*'s (1997) study consisted of a series of four experiments. The first used a detection task and measured both the accuracy of both colour and location responses. The second was identical except that instead of reporting the target's colour (e.g. "was the target green?") participants reported the target's shape (e.g. "was the target an O?"). Using a string of five differently coloured letters, in experiment one, one of the three middle letters was replaced by an O and one adjacent distractor colour was replaced by green. In experiment two, either the O was green or one of the remaining middle position letters was green with the O being a distractor colour. Results from both experiments found that the distribution of illusory conjunctions appeared to show a peak approximately at the midpoint between the actual locations of the two features. They suggested that this finding supported the *spatial averaging* rule of the *aggregate* model.

However, their results could be interpreted in two ways theoretically and so in experiment three they tested whether the perceived location of illusory conjunctions was

as a result of a single distribution or an aggregate of two (shape and colour). Although identical in format to experiments one and two except that they increased the interletter distance. They found significantly more responses located around the midpoint than were located around both flanking positions. From this, they concluded that these results were consistent with the aggregate model. Taken together, experiments one, two and three indicated that location information obtained from both colour and shape are integrated to determine the location of an object in the visual field. Thus, the difference in mean locations between correct rejections and illusory conjunctions suggests that both features contribute to the perceived location of the illusory conjunction. In all three experiments, they suggest that the distractor, whether colour or shape, may have been difficult to ignore and provided an undue influence on location perception.

Experiment four was designed to minimise this by using multiple target colours and letters, with location responses being made on the basis of detection of both shape and colour rather than on one feature (shape) or the other (colour). They found that changing from a detection task to an identification task did not alter the result that illusory conjunctions were spatially displaced compared with correct responses. Thus, the distribution of the perceived location did not imply that illusory conjunctions are perceived either *near* the colour or *near* the shape. Rather, both features seemed to have an equal influence on the perceived location of the integrated object.

Hazeltine *et al* (1997) further suggested that the equality of influence found for both constituent features indicates that binding may occur via a weighted spatial average of the locations of the two features that contribute to the illusory conjunction. They cite the example: if a target (for instance a blue T) can be located at one of several positions along a horizontal axis, the visual system may have information that blue is located at position seven and T at position five. This would result in the object being perceived at position $(7a + 5b)/2$, where a and b are weighting constants. The perceived locations of each of the two features would show dispersal around their actual locations so that over trials, these would form a normal distribution (by the central limit theorem) and the mean of this distribution would be at the midpoint between the two features. Therefore, they rejected both *FIT*s random and the *unitary* model.

However, on closer examination of their results, in experiment one, where the interletter distance was 36 pixels, mean location responses were 13.7 pixels from the target and for the identification task in experiment four, they were 23.76 pixels from the target (or 12.25 pixels from the distractor). Only in experiment two was the mean

response of 16.86 at the midpoint of 17 pixels and suggestive of spatial averaging. For experiments one and four, the results may be indicative of a unitary model with bias. For example, Tsal & Baraket (2005) found that even with focused attention, a bias of 50% of the target width was apparent and this increased to 100% when attention was widely distributed (4^o of visual angle). At a visual angle of 2^o, one might expect a bias of 75% of target width or 12.75 pixels. This would indicate that for Hazeltine *et al's* (1997) experiment one, it was the target shape that unitarily provided the location information while for experiment four, it was the distractor colour. Therefore, there is some indication that Hazeltine *et al's* (1997) findings are not as clear-cut as suggested.

In an effort to resolve this issue, the following three experiments examine in similar detail the perceived location of the individual features contributing to an illusory conjunction. Experiment one is a near replication of Hazeltine *et al's* (1997) experiment four, while experiment two extends the stimulus strings further into parafoveal vision in an effort to provide a greater number of illusory conjunction responses. Experiment three includes a time delay in order to investigate location bias more thoroughly.

2.1.2 METHOD

2.1.2.1 DESIGN

A repeated measures design was used with one factor: the distance between the target and distractor with two levels, near and far. A partial report paradigm was used in which both colour and shape for the target only were reported together with target location. A total of 600 experimental trials and 48 practice trials were provided over two days. These were divided into six groups of 100 trials and two groups of 24 practice trials. Three groups of 100 trials (300) and one group of 24 practice trials were conducted on day one and the remaining 300 trials and 24 practice trials on day two. Each group of 100 trials lasted for approximately fifteen minutes and participants were given a five-minute rest between each of the three groups. The independent variable was the distance between the target and distractor (*near* or *far*). The dependent variables were the error rates for identification of the target, and the exact perceived location of the target (in pixels).

2.1.2.2 PARTICIPANTS

Participants were all members of Sussex University, whose occupations ranged from senior research fellow to technician. These were four males and four females with ages ranging from 24 to 55 years. All participants had normal or corrected to normal visual

acuity. No participant was aware of the purpose of the experiment. Payment for participation was made as follows: £10 for taking part (£5 for each day) plus a bonus payment for responding correctly to both the identification and location of the target stimuli, calculated as follows: for target identification accuracy, every correct identification over 50%, generated 1p; for target location accuracy, if the selected location was within 4.5 pixels to either the left or right of the centre of the target letter, a bonus of 2p was generated. Participants were made aware of the bonus scheme before the commencement of the experiment to encourage accuracy.

2.1.2.3 APPARATUS/MATERIALS

Stimuli were displayed and responses recorded using a custom-written programme in Visual Basic 6, run on a Viglen Genie 2 Plus with a 17 inch CRT colour monitor. Screen resolution was 1024x768 pixels (60 hertz refresh rate). A chinrest was used to stabilise the viewing distance at 70cm so that 1cm on the display corresponded to 0.82^{o} of visual angle. Responses were made using a three-button Logitec mouse.

2.1.2.4 STIMULI

The stimulus display was comprised of both target and distractor letters and colours and were similar to those used by Hazeltine *et al's* (1997), presented on a white background. The distractor letters consisted of a set of 5 letters taken from the following 4 groups of letter strings, randomly selected: OSGCU, UGCSO, GCSOU and SUOGC. Each distractor letter was also randomly assigned a colour from one of four possible colour series: 1) orange, grey, green, purple and pink; 2) green, pink, grey, orange and purple; 3) purple, orange, green, pink and grey and 4) pink, green, orange, purple, and grey. The CIE (Commission Internationale de l'Eclairage) co-ordinates for each stimulus colour are shown in table 2.1.

The target was comprised of one of two letters (T or X) and one of three colours (red, blue or yellow). On each trial, the target letter and its colour were selected randomly from these possibilities. In addition, the colour of a distractor letter in one of the remaining central positions was replaced by one of the remaining two target colours. In 66 of the 100 trials in each group, the target letter and one of two target colours were placed next to each other in either positions 2 and 3, or 3 and 4 (near condition). In the remaining 34 trials, they were placed in positions 2 and 4 (far condition). For example, in the *near* condition, if a blue X was placed in position 3, then the distractor letter in either

position 2 or 4 was coloured either red or yellow. Figure 2.1 shows the various target and distractor positions for both conditions.

Colour	CIE *x* co-ordinate	CIE *y* co-ordinate	Luminance (cd/m^2)
Red	0.61	0.35	4.27
Blue	0.16	0.10	2.43
Yellow	0.45	0.50	18.91
Green	0.38	0.53	3.36
Orange	0.54	0.42	7.36
Magenta	0.30	0.17	6.09
Purple	0.32	0.19	1.54
Grey	0.34	0.34	4.60

Table 2.1: CIE colour co-ordinates for each stimulus colour

Letters subtended approximately 0.53^o vertical by 0.45^o horizontal (20 x 17 pixels) of visual angle at a viewing distance of 70cm. Each letter was separated horizontally from its neighbour by approximately 0.90^o of visual angle (34 pixels) centre to centre. It should be noted that these visual angles are marginally less than those reported by Hazeltine *et al* (1997) who stated visual angles of 0.71^o vertical by 0.54^o horizontal for each letter with an interletter distance of 1.21^o. The letter strings were placed in either the upper or lower visual field. The regions were 4.25^o of visual angle to the left or right and extended from 0.90^o to 1.80^o vertically above or below the fixation point. Random positioning was used to prevent any strategies being used by participants.

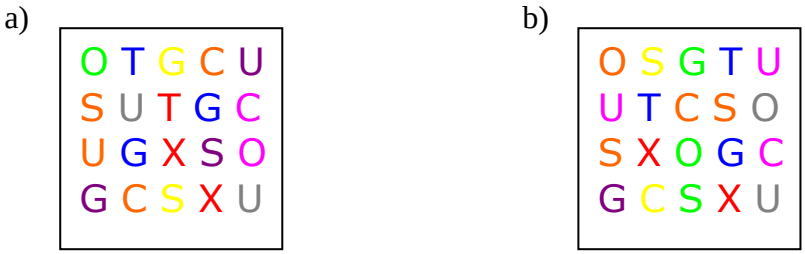

Figure 2.1 Target and distractor positions used a) for the near condition and b) for the far condition.

2.1.2.4 PROCEDURE

Participants were tested individually and the apparatus was arranged so that a viewing distance of approximately 70cm was achieved. Instructions were provided as to the task requirements and any questions raised were answered only if the naivety of the participant remained intact. The experiment was run over two days and consisted of one

block of 24 practice trials on the first day and one group of 24 practice trials on the second. Each practice trial was identical to the experimental trials except that the stimulus display was visible for 500 msecs in the first practice session but only visible for 200 msecs on the second day. This was to allow participants to become accustomed to the task. On completion of each trial, the stimulus display with the participants' location response superimposed was visible for 1sec. Illusory conjunctions are formed when attentional resources are limited but individual features are correctly identified. However, if presentation is too brief there is a risk that feature errors will occur because the quality of the sensory information is too low (e.g. Garner, 1974). Therefore, experimental exposure durations were controlled separately for each participant to reduce the rate of feature errors to approximately 10%. This was determined from the practice trials as follows: when error rates of less than 20% were recorded, the duration was reduced to 52[6] msec; when error rates fell between 20% and 40%, the duration was reduced to 104 msec; and when error rates greater than 40% were recorded, the duration was reduced to 156 msec.

Each experimental trial proceeded as follows: first, a fixation cross appeared in the centre of the screen for 500ms followed by the stimulus display that appeared for 52 to 156 ms to ensure that the initial, unlimited capacity stage of perceptual analysis is being assessed and to preclude eye movements. This was followed by a 52 msec blank white noise screen. Next, a row of location boxes appeared along the same horizontal axis as the stimulus. Each box subtended 0.21^{o} (5 x 5 pixels) on each side and was separated by approximately 0.60^{o} of visual angle (14.5 pixels), this being exactly 50% of the distance between the stimulus letters. Thus, one box appeared where the centre of each letter had been displayed and one between adjacent letters. This spacing pattern of boxes was continued across the width of the screen to prevent cuing (see figure 2.2).

Participants first indicated the perceived location of the target by using the mouse to move the arrow cursor to one of the boxes. They then clicked one of the three mouse buttons (left = unsure; middle = fairly sure; right = very sure) to indicate how confident they were in their judgement. No location response was registered unless one of the boxes was clicked. Immediately following this, six target identification buttons appeared on the screen arranged in two rows of three each. The top row represented the target letter T and the bottom row, the target letter X. Dixon (1986) found that following the

[6] These stimuli durations (multiples of 52 msec) were used to coincide with the Windows operating system refresh rate of 52 msec.

stimulus string with another alphanumeric string can cause errors, therefore the target letters were not displayed on the response boxes. Each of the three columns was coloured red, yellow and blue, to represent each of the three target colours respectively. Thus, had a blue T been perceived, participants would click on the third button of the top row. Again, participants used one of the three mouse buttons to indicate how confident they were. The actual mean result for both location and identification together with the weighted confidence result was then displayed. This was followed by the start of the next trial. Participants were told that accuracy was most important and to take their time as speed was not an issue.

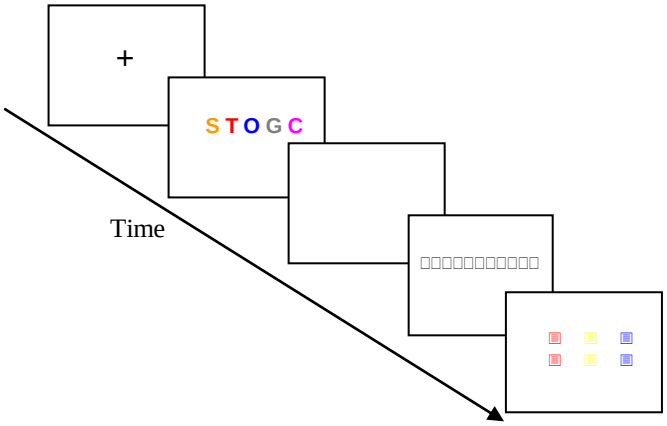

Figure 2.2: Representation of trial procedure (not to scale)

On completion of all six groups of 100 trials, the amount of bonus earned was displayed. Participants were debriefed then thanked for their co-operation and a copy of the experimental rationale together with the results was offered once all the data had been collected and analysed.

2.1.3 RESULTS

2.1.3.1 OBJECT IDENTIFICATION

Both conditions (*near* trials in which the distractor colour was adjacent to the target letter; and *far* in which the distractor colour was separated from the target letter by one intervening letter) resulted in six possible response types. Target letter identification categories showed whether participants either reported the correct letter or the incorrect letter. Target colour identification categories indicated whether participants correctly identified the target colour (colour correct), identified the distractor colour or reported a target colour that was not present in the trial (colour incorrect). Table 2.2 records the

percentage means for the resulting six response categories for both the *near* and *far* condition across participants.

Participants were accurate, in the sense of correctly identifying both the target letter and target colour, on 85 % of the total 396 *near* trials and 90% of the total 204 *far* trials. Responses categorised as *letter correct/distractor colour* are classed as illusory conjunctions and amounted to 6 % and 4% of *near* and *far* trials respectively. Those categorised as *letter correct/colour incorrect* (feature error) occurred on 2% of both types of trials. All letter incorrect responses (whether the correct colour, the incorrect colour or distractor colour was chosen) represented 2%, 1% and 3% of *near* trials. For *far* trials these represented 4%, 0.12% and 0.55% respectively.

Condition	**Target Letter Correct**			**Target Letter Incorrect**		
	Colour Correct	**Distractor Colour**	**Colour Incorrect**	**Colour Correct**	**Distractor Colour**	**Colour Incorrect**
Near	85.44 (9.18)	5.53 (3.43)	2.46 (1.82)	2.18 (2.68)	3.47 (1.25)	0.92 (1.01)
Far	89.82 (8.79)	3.92 (3.08)	1.90 (2.29)	3.68 (3.66)	0.55 (0.66)	0.12 (0.35)

Table 2.2: Percentage mean (and standard deviation) of recorded identification responses for both the near and far conditions.

A one-way repeated measures ANOVA with two levels of interletter distance was performed on these data. Overall, the main effect of interletter distance for both the *near* (approximately 34 pixels) and *far* (approximately 68 pixels) conditions within each category was non significant ($F(1,7) = 0.51$, $p>.05$), indicating that the distance between the target and distractor had no appreciable effect on whether participants were able to correctly identify the target, made illusory conjunctions, or made feature errors. However, distance did have a significant main effect on the number of responses for each of the six identification categories ($F(1.672, 11.70) = 5.07$; $p<.05$). To determine whether this result related directly to illusory conjunction responses, a pairwise comparison between *letter correct/distractor* colour for both conditions was made and indicated that significantly more illusory bindings occurred when the distractor was placed close to the target ($t(7) = 3.04$; $p<.05$). This is consistent with research indicating that proximity has a significant effect on the number of illusory bindings made (e.g. Ivry &Cohen, 1989, Ashby *et al* 1997).

A proportion of the illusory conjunctions recorded may also be attributed to guesses. Treisman & Schmidt (1982) suggested that for trials where participants have recorded a confident response, they have perceived a genuine perceptual phenomenon rather than perceiving two individual features and then guessing that they formed part of

the same object. For this experiment, although three possible confidence ratings were offered, only three of the eight participants used the *unsure* rating. Therefore, only *confident* and *not confident* ratings were analysed. In the *near* condition, ratings across participants were *confident* in 95% of *both correct* trials; 85% of *letter correct/distractor colour* trials but only in 15% of *letter correct/colour incorrect* trials. This strongly implies that participants believed they had perceived an object, rather than perceiving a colour and shape present in the display but guessing that they were conjoined (see table 2.3). Confidence ratings for all *incorrect letter* trials were omitted due to the very small amounts of data.

Letter Correct	**Near**		**Far**	
	Confident	**Not Confident**	**Confident**	**Not Confident**
Colour Correct	94.87 (4.71)	5.08 (4.71)	95.60 (2.41)	4.23 (2.41)
Distractor Colour	85.28 (19.19)	37.84 (32.72)	93.46 (4.42)	6.54 (4.42)
Incorrect Colour	14.58 (12.35)	85.42 (12.35)	3.00 (10.61)	97.00 (0)

Table 2.3: Mean (and standard deviation) confidence ratings expressed as a percentage for each of the three letter correct response categories in the near and far conditions.

Similar results were obtained for the *far* condition. Confidence ratings across participants were 96% for *both correct*; 93% for *letter correct/distractor colour*; and 3% for *letter correct/colour incorrect* trials. Only one participant made any *both incorrect* responses for which all were rated as *not confident* (100%). Again, the high proportion of *both correct* and *illusory conjunction* responses with a correspondingly low proportion of the remaining confidence ratings indicate that true feature binding errors were made. When only "confident" responses were analysed between *letter correct/distractor colour* responses for the *near* and *far* conditions, they also showed that significantly more illusory bindings occurred when the distractor was placed close to the target ($t(7) = -4.04$; $p<.01$), indicating that *not confident* responses did not make a significant contribution to the result.

2.1.3.2 OBJECT LOCATION

Normalisation of raw scores was computed by subtracting the perceived location from the actual target location to give a $\pm$ result in pixels. Negative values represent response locations that moved away from the target in the opposite direction to the distractor. Positive values represent response locations that moved from the target towards the distractor. Data were analysed as the pixel dispersal from the centre of the

target (0 pixels). The mean perceived locations for all six response categories across participants are shown in table 2.4.

In the *near* condition, the distractor was approximately 34 pixels from the target. For the *far* condition, the distractor was approximately 68 pixels from the target with an intervening letter placed midway between the two at 34 pixels. For both conditions, all correct colour responses showed a shift in the direction of the distractor except for *letter incorrect/colour correct* responses in the *far* condition. However, when colour errors were made, regardless of whether the correct letter was selected, only *near* trial responses moved in the direction of the distractor. *Far* trial responses shifted in the opposite direction. All four distractor colour response categories shifted away from the target in the direction of the distractor.

Condition	**Target letter**	**Target colour**		
		Colour correct	**Distractor colour**	**Colour incorrect**
Near	Letter correct	-7.34 (2.88)	18.2 (7.98)	5.82 (22.75)
	Letter incorrect	-2.43 (7.09)	27.03 (9.77)	21.17 (23.46)
Far	Letter correct	-1.24 (1.65)	10.66 (11.77)	-5.73 (18.46)
	Letter incorrect	1.78 (6.77)	16.38 (32.64)	-1.88 (5.30)

Table 2.4: The mean (and standard deviation) of perceived location (in pixels) for each of the six response categories for both near and far conditions.

Bias, whether moving towards or away from the distractor, showed a high degree of variability between response categories. For example, in the *near* condition *both correct*; *letter incorrect/colour correct* and letter correct/colour incorrect responses, were perceived within the target area (approximately 17 pixels). However, *letter correct/distractor colour* responses were perceived at 18 pixels from the target and thus close to the midpoint between the target and distractor (located at 17 pixels). A similar bias was also recorded for *letter incorrect/colour incorrect* responses, which were perceived 21 pixels from the target and close to the midpoint. Incorrect letter/distractor colour responses were perceived to be even further away from the target at 27 pixels.

Similarly for the *far* condition, *both correct*; *letter incorrect/colour correct*; letter correct/colour incorrect and both incorrect responses were perceived within the target area (approximately 17 pixels). However, *letter incorrect/distractor colour* responses were perceived at 16.38 pixels from the target, which placed the perceived location midway between the target and an intervening letter and not midway between the target at the distractor which was located at 34 pixels and centred over the intervening letter. The

perceived location of *letter correct/distractor colour* responses was closer to the target at 10.66 pixels.

However, caution needs to be exercised when interpreting the data due to the small number of data points for all but the *both correct* responses. The two categories of most interest, *both correct* and *letter correct/distractor colour* (illusory conjunctions) are shown in figures 2.3a and b. These results, with the exception of the *letter incorrect/distractor colour* category in the *far* condition, were confirmed by a series of 2-tailed planned comparisons with Bonferroni correction (giving an observed significance level of 0.004). This corrected significance level was used to report statistical results. Each of the six response categories in both conditions were compared with the absolute target position. The Kolmogorov-Smirnov test for normality showed that the perceived location for all response categories in the *near* and *far* conditions was normally distributed except for *incorrect letter/distractor colour* and *letter incorrect/colour incorrect* categories in the *far* condition for which a nonparametric test were performed (Wilcoxon-Mann-Whitney *T*).

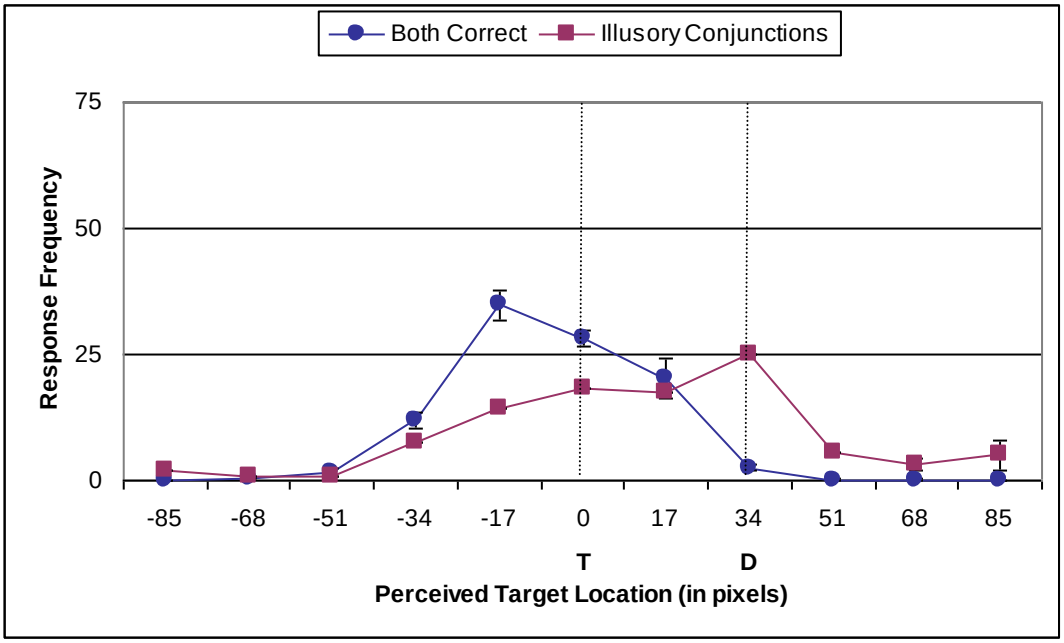

Figure 2.3a: The percentage frequency of both correct and illusory conjunction (target letter correct/distractor colour) responses for the near condition shown as the distance in pixels from the actual location of the target. T represents the target position (0 pixels) and D represents the distractor position (34 pixels). Error bars = +/- 1 standard error.

For the *near* condition, while there were non-significant differences between the target position and the perceived location for *incorrect letter/colour correct* ($t(7) = 0.72$, $p>0.004$), *both incorrect* ($t(7) = 2.56$, $p>.004$), and *letter correct/colour incorrect*

responses ($t(7)$= -0.97; p>.004), the remaining response categories all showed that the perceived location was significantly further from the actual target location: *both correct* ($t(7)$ = -7.22, p<0.004); *letter correct/distractor colour*($t(7)$ = 6.45, p<.004); and *letter incorrect/distractor colour* were all significant ($t(7)$ = 7.82, p<.004).

For the *far* condition, all identity categories except *letter correct/distractor colour* ($t(7)$ = 2.56, p <0.004) showed that the perceived location was not significantly different from the actual target location: *both correct* ($t(7)$ = -2.12, p>.004; *letter correct/ distractor colour* ($t(7)$ = 2.56, p>.004); *letter correct/colour incorrect* ($t(7)$ = -0.88, p>.004; *letter incorrect/colour correct* ($t(7)$ = 0.74, p>.004); *letter incorrect/distractor colour* (T = -1.46, p>.004) and *both incorrect* (T = -1.00, p>.004). The unexpectedly non-significant result for the *incorrect letter/distractor colour* category, when the mean perceived location was 16 pixels from the target, can be accounted for by the mean perceived location of 93 pixels for one participant. When removed, the overall mean location for this category is 5.43 pixels providing a non significant result ($t(7)$ = 1.29, p> 0.004.

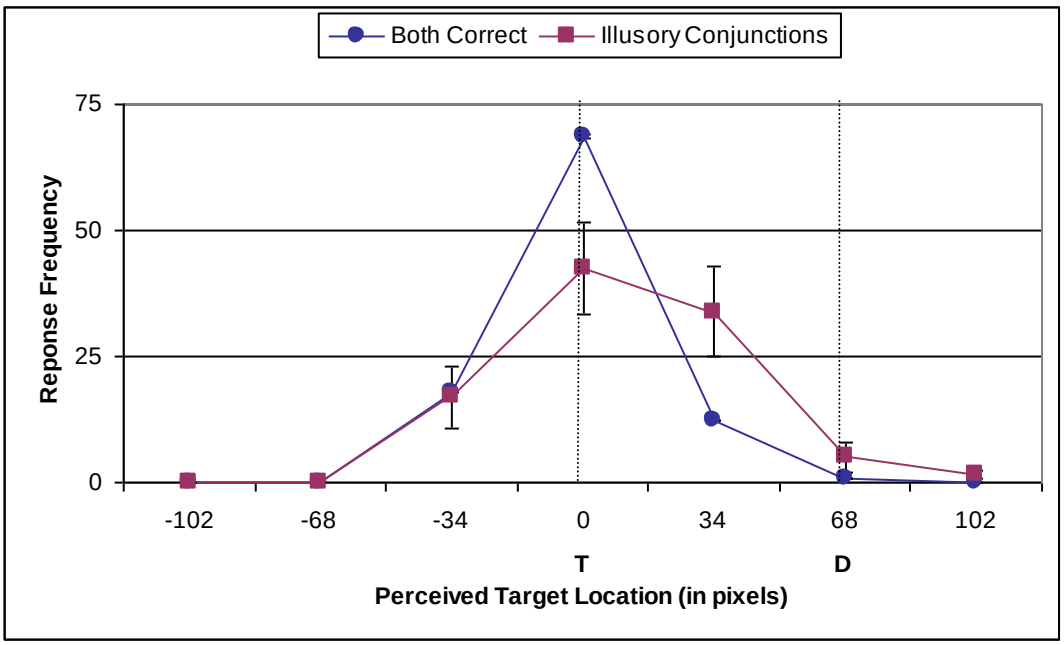

Figure 2.3b: The percentage frequency for both correct responses and illusory conjunction (target letter correct/distractor colour) for the far condition shown as the distance in pixels from the actual location of the target. T represents the target position (0 pixels) and D represents the distractor position (68 pixels). Error bars = +/- 1 standard error.

These results indicate that the perceived location of responses where the distractor colour was chosen, regardless of whether the letter was correct or incorrect, shifts in the direction of the distractor. However, while this shift is more pronounced in the *near*

rather than the *far* condition, both show a systematic deviation away from their originating position with *letter correct* responses showing some shift towards the distractor colour and *letter incorrect* responses showing considerable shift away from the distractor colour towards the target letter.

However, when only *letter correct/distractor colour* responses that were recorded as *confident* were analysed, the mean perceived location of illusory conjunctions for the *near* condition was 14 pixels away from the target in the direction of the distractor. This indicated that the location of the illusory conjunction was not at the midpoint between the target and distractor but perceived somewhat closer to the target. For the *far* condition, this shift closer to the target is even more evident at 2 pixels instead of the 11 pixels found when all data is included. This indicates that the deviation away from the target is less pronounced than the initial analysis would suggest although it should be noted that the variance between individual participants closely resembled that found when data was analysed across participants (6.88 and 9.24 respectively).

2.1.4 DISCUSSION

Results from experiment one indicate that target identification accuracy, where both the target shape and colour were correctly identified, was 85% for trials in which a second possible target colour (distractor colour) was placed next to the target object. Trials in which an intervening non-target item was placed between the target and distractor provided 90% *both correct* responses. These results were similar to those of Hazeltine *et al* (1997) who obtained 81% and 89% respectively. This high percentage of *both correct* responses indicates that feature integration was correctly achieved at stimulus presentation durations as low as 52 msec. This is comparable with past research using the illusory conjunction paradigm. For example, Cohen (1997), using display presentations as low as 33 msecs, found that accurate coding for between-dimension conjunctions was achieved at search times significantly faster than for trials in which separate target values of colour and form were present (i.e. within dimension for form alone, where all items shared the same colour but with a unique target shape; for colour alone, where all items had the same shape but the target had a unique colour; and between-dimensions where both the target colour and shape were unique with homogeneous distractors). He suggested that the faster and more accurate coding of between-dimension trials suggests that colour and shape are not independent at the very early stages of perceptual analysis.

However, in the above experiment, only 27% of correctly identified targets in the *near* condition were also correctly located. This proportion may have resulted entirely from the one third of trials in which the target was placed closest to the fixation point. If this is the case, then while features can be correctly bound as suggested by Cohen (1997), only coarse (directional) location information is available when attention is widely distributed (e.g. Prinzmetal *et al*, 1998; Treisman, 1993; Tsal & Baraket, 2005; Tsal & Meiran, 1993).

It is difficult to determine whether all illusory conjunction responses can be seen as true feature binding errors, or whether some of these responses can be attributable to guesses. While different procedures have been developed to correct for guessing, none is able to accurately distinguish between those reports that are genuine illusory conjunctions and those that are guesses. Therefore, provided that a significant proportion can be attributable to true errors in binding, then all such reports are accepted (see pages 31-35 for a full discussion of this topic). One method that has been proposed as more robust is multinomial modelling. Such models allow independent estimation of the probabilities of correctly perceiving two features from the probability of correctly binding the same two features (e.g. Ashby *et al*, 1996; Prinzmetal *et al*, 1995; Prinzmetal *et al*, 2002). Regardless of the method used, in all illusory conjunction studies examined (with the exception of Donk, 1999, 2001), researchers have agreed that while the majority of illusory conjunctions can be seen as true feature binding errors, some proportion can also be attributed to guessing. However, Prinzmetal *et al* (2002), when testing such models, found that where the same colour is not used for more than one item within a stimulus, guessing colour was effectively zero and a colour guessing parameter need not be included in the model.

A further point to note was that confidence ratings were used to examine the adequacy of these models. Confidence ratings show whether an illusory conjunction was actually perceived or whether the shape and colour were separately identified and then it was guessed that both features comprised a single object. Prinzmetal *et al* (2002) found that multinomial models accurately reflected trial-by-trial confidence ratings. If this is the case then confidence ratings should provide a simpler and similarly effective method for determining this parameter.

For this experiment in the *near* condition, while a very high proportion of *both correct* and *illusory conjunction* responses were rated as confident, a much greater proportion of *letter correct/colour incorrect; incorrect/colour correct; incorrect*

letter/distractor colour and *both incorrect* responses were rated as not confident. Similar results were found for the *far* condition despite there being a letter placed between the target and distractor. Thus, a very high proportion of *both correct* and *illusory conjunction* responses were rated as confident whereas for those responses in which either one or both features were incorrect, confident ratings were considerably reduced. Therefore, it was concluded that participants perceived illusory conjunctions as genuine phenomena rather than perceiving a colour and shape that were present in the display but guessing that they were bound into a single object.

A number of researchers have also suggested that illusory conjunctions occur more frequently when the target and distractor are placed close together (the adjacency effect), indicating that separate processing of feature detection and feature binding is taking place (e.g. Cohen & Ivry, 1989; Cohen & Shoup, 2000, Hazeltine *et* al, 1997; Keele *et al*, 1988; Prinzmetal & Mills-Wright, 1984; Rapp, 1992, Seidenberg, 1987). The presence of an intervening letter located between the target and distractor in the *far* condition would be expected to significantly reduce the number of illusory conjunctions reported. As expected, results indicated that this was the case confirming the dissociation of feature detection and feature binding and contrary to Treisman & Schmidt's (1982) finding of no such effect.

If only a single feature contributes to the perceived location of a bound object as predicted by the *unitary* rule, it would be expected that colour errors would be perceived around the veridical position of their respective source: *letter correct* responses should be centred around the target's position and *letter incorrect* responses either around the distractor's position if the adjacent colour was chosen, or randomly if neither the letter nor colour response was actually present in the display. Statistically, considerable structure to the mean perceived location of colour correct responses was found across participants for both conditions, regardless of whether the correct or incorrect letter was perceived, with all location responses falling on the target. Similar structure was obtained for *letter correct/colour incorrect* although a high degree of variance in the data was noted, indicating that the perceived location was random, albeit within the confines of the stimulus array. This would indicate that the source of the location information is indeed a single feature.

However, contrary to expectations, *both incorrect* responses in the *near* condition were perceived close to the midpoint between the target and the distractor, again with a high degree of variance, with *both incorrect* responses in the *far* condition being

perceived on the target. Responses in which the incorrect letter and distractor colour were chosen were not perceived on or even close to the actual position of the distractor colour. Rather, in *near* trials, where interletter distance was 36 pixels, they were perceived approximately 11 pixels from the distractor colour in the direction of the target and conversely in the *far* condition, where the interletter distance was 72 pixels, they were perceived approximately 16 pixels from the target towards the distractor again with a high degree of variance. However, it should be noted that not all of the variance is necessarily attributable to perceptual factors. For example, skill in using a mouse, memory limitations and indecision may all have contributed as well.

Illusory conjunction responses were also contrary to expectations for the *near* condition. These were perceived approximately midway between the target and the distractor and are comparable with Hazeltine *et al's* (1997) findings, thus supporting the aggregate model (Ashby *et al*, 1996). This suggested that the perceived location of an illusory conjunction is made up of location information randomly selected from the location information obtained from both features. Over trials, the perceived locations for both colour and shape should form a normal distribution centred round the midpoint between both features. However, when only confident responses were analysed, it was found that the perceived location moved closer to the source, indicating that the aggregate model may not be a true reflection of the data. This was not the case for the mean perceived location of illusory conjunctions for the *far* condition which was approximately 11 pixels from the target in the direction of the distractor. This is considerably closer to the target than the midpoint of 36 pixels. Indeed, the mean perceived location for only the "confident" responses was 2 pixels from the target and indicated that shape was likely to be the source of the location information, providing support for the second WTA model. As Hazeltine *et al* (1997) did not analyse *far* data, citing a possible confound caused by the intervening letter, nor make any attempt to correct for this, no comparison can be made with their data.

While the results for illusory conjunction responses in the *near* condition lend some support for the *aggregate* model, it is difficult to make any but tentative conclusions when so little data were obtained for this response category (5.53% and 3.92% of responses respectively). Therefore, experiment two will address this issue by placing the position of the stimulus array further into parafoveal vision to try to increase the number of illusory conjunction responses each participant makes.

2.2 EXPERIMENT 2

2.2.1 INTRODUCTION

In experiment one, it was difficult to draw any definite conclusions because of the very small amount of data obtained for all response conditions except where both target features were correctly identified. This may have been due to the positioning of the stimuli. While these were located in parafoveal vision, this was still reasonably close to fixation (2.01^o of visual angle). Parafoveal vision extends from approximately 1^o to 5^o of visual angle. Therefore in experiment two, fuller use was made of parafoveal vision. One consideration when extending stimuli into parafoveal vision is the effect this will have on colour perception and whether individual colours could be just as easily detected. When colour stimuli are not viewed in central fixation, they not only impinge on photoreceptors in the peripheral retina (rods) but there is a reduction in density (saturation) of colour mediating photoreceptors (cones) resulting in the perceived colour taking on a progressively bleached appearance (e.g. Kinney, 1979). However, while the reduction in saturation occurs causes each of the stimuli colours to appear paler, it has been demonstrated that the perceived hue remains the same and therefore should not affect detection of the target (Fuller & Carrasco, 2006). Further, the white background makes colours appear to be darker than they actually are and it is hoped that this will mitigate any effects of bleaching.

2.2.2 METHOD

2.2.2.1 DESIGN

The experimental design for experiment two was identical to that for experiment one with one exception. While inter-letter distance (*near* and *far*) and the vertical positioning of the stimuli (0.90^o to 1.80^o above or below the fixation point) remained the same, to promote the occurrence of binding errors, the positioning of stimuli along the horizontal axis was extended from 2.13^o (4.25^o centred round fixation) to 4.66^o of visual angle from the point of fixation. Participants, apparatus/materials, stimuli and the procedure used were all identical to those used for experiment one.

2.2.3 RESULTS

2.2.3.1 OBJECT IDENTIFICATION

The overall mean percentage for the six response types for both the *near* and *far* conditions are shown in Table 2.5. On average, participants were accurate (in terms of correctly identifying both the target letter and target colour) on 49% of the total *near* trials and 52% of the total *far* trials. Responses categorised as *letter correct/distractor colour*

(illusory conjunctions) occurred on 22% of the *near* condition trials and 20% of the *far* condition trials.

Responses categorised as *letter correct/colour incorrect* accounted for 10% and 10% of *near* and *far* trials respectively. Letter incorrect responses comprised 7% of *near* and 7% of *far* trials when the correct colour was chosen; 9% and 7% respectively where the distractor colour was chosen; and 4% and 3% respectively when the incorrect colour was chosen. Pairwise comparisons with Bonferroni correction gave an adjusted significance level of 0.025.

Condition	Target Letter Correct			Target Letter Incorrect		
	Colour Correct	Distractor Colour	Colour Incorrect	Colour Correct	Distractor Colour	Colour Incorrect
Near	48.61 (6.05)	21.59 (1.87)	10.01 (1.78)	7.10 (4.30)	8.55 (25.62)	4.13 (1.10)
Far	52.38 (5.93)	20.40 (4.58)	9.74 (2.02)	7.35 (3.71)	6.86 (2.70)	3.31 (2.34)

Table 2.5: Percentage means (and standard deviation) of recorded identification responses in both near and far conditions.

The distance between the target and distractor had no significant main effect on the type of response made, for both *near* (approximately 34 pixels) and *far* trials (approximately 68 pixels), ($F(1,7) = 0.98$, $p>.05$) indicating that interletter distance did not affect participants' ability to correctly identify the target, make an illusory conjunction or a colour error. Nor did distance elicit an overall effect on the number of responses for each of the six identification categories ($F(1.096, 7.669) = 1.61$, $p>.05$). Further, the percentage of illusory conjunction responses for both the *near* and *far* conditions was 22% and 20% respectively and unlike experiment one, indicated that no adjacency effect was present. This was confirmed by a pairwise comparison between *letter correct/distractor colour* responses for both conditions ($t(7) = 0.88$; $p>.025$).

Letter Correct	Near		Far	
	Confident	Not Confident	Confident	Not Confident
Colour Correct	74.36 (20.64)	25.64 (20.64)	73.02 (29.07)	26.82 (17.81)
Distractor Colour	67.19 (13.80)	32.81 (13.80)	62.98 (10.78)	37.02 (10.78)
Incorrect Colour	57.06 (20.69)	42.94 (20.69)	53.50 (4.50)	46.50 (6.02)

Table 2.6: Mean (and standard deviation) confidence ratings expressed as a percentage for each of the three letter correct response categories in the near and far conditions.

Confidence ratings were analysed to determine what proportion of illusory conjunction responses could be counted as true feature binding errors. As for experiment one, three possible confidence ratings were offered. However, as only four of the eight participants used the *unsure* rating, only *confident* and *not confident* ratings were

analysed. In the *near* condition, participants rated their responses as confident for 74% of *both correct* responses; 67% of *letter correct/distractor colour* responses; and 57% for *letter correct/colour incorrect* responses. Therefore, while a significant proportion of *both correct* and *illusory conjunction* responses were rated as confident, similar numbers of *confident* and *not confident* ratings were given for those responses in which either one or both features were incorrect. This would indicate that on a proportion of trials, participants perceived a colour and shape present in the display but guessed that they were conjoined (see table 2.6).

Similar results were obtained for the *far* condition. Confident ratings were 73% for *both correct*; 63% for *letter correct/distractor colour*; and 54% for *letter correct/colour incorrect* trials. Again, the proportions of confident *both correct* and *illusory conjunction* responses ratings indicate that while true feature binding errors were made, a proportion of these were probably due to guessing. When only confident responses were analysed between *letter correct/distractor colour* for both conditions, they also showed that illusory bindings were no more likely to occur when the distractor was placed close to the target ($t(7) = 1.69$; $p>.025$), indicating that *not confident* responses did not alter the initial finding.

2.2.3.2 OBJECT LOCATION

Normalised raw scores were analysed as the pixel dispersal from the centre of the target (0 pixels). Table 2.7 shows the mean overall perceived locations (and their associated standard deviations) for all six response categories in both conditions.

Condition	Target Letter	Target Colour		
		Colour Correct	Distractor Colour	Colour Incorrect
Near	Letter correct	1.89 (4.32)	21.57 (3.92)	13.82 (3.66)
	Letter incorrect	0.96 (6.73)	19.43 (8.76)	14.54 (7.64)
Far	Letter correct	-0.06 (4.91)	16.24 (6.17)	12.46 (10.94)
	Letter incorrect	0.94 (10.32)	23.16 (10.65)	5.48 (13.04)

Table 2.7: The mean (and standard deviation) of perceived location for each of the six response categories for both near and far conditions.

The data indicate that for the *near* condition, *both correct* responses were perceived over the target area (which encompassed approximately 17 pixels). For the *far* condition, *both correct* responses together with *letter incorrect/colour incorrect* were also positioned over the target. The remaining colour error responses were perceived approximately 13.5 pixels from the target. Illusory conjunction responses (*letter correct/distractor colour*) in the *near* condition were perceived to be close to the midpoint

between the target and the distractor (17 pixels). Similarly, illusory conjunction responses for the *far* condition showed a mean perceived location of +16 pixels. However, in this instance, it would place the illusory conjunction midway between the target and the intervening letter. Results suggest that in both the *near* and *far* conditions, illusory conjunction responses, whether *letter correct* or *letter incorrect*, are perceived to be only marginally nearer the distractor colour than all other responses, with the exception of *letter correct/colour incorrect*, which were perceived close to the target in the *far* condition but marginally further towards the distractor in the *near* condition. These findings would indicate that while shape is most instrumental in determining an object's location in the *far* condition, both features may have contributed to perceived location for the *near* condition. When only 'confident' illusory conjunction responses are analysed, these indicate that the mean perceived location was 18 pixels for the *near* condition and 22 pixels for the *far*. This bias towards the distractor for *near* illusory conjunction responses would not only be expected if the location of the illusory conjunction was perceived to be somewhere close to the midpoint between the two objects as suggested by Hazeltine *et al* (1997). However, when both conditions are considered, the data would indicate that on some occasions it was the shape that provided this information and on others, it was the colour, as would be expected for a *unitary* rule.

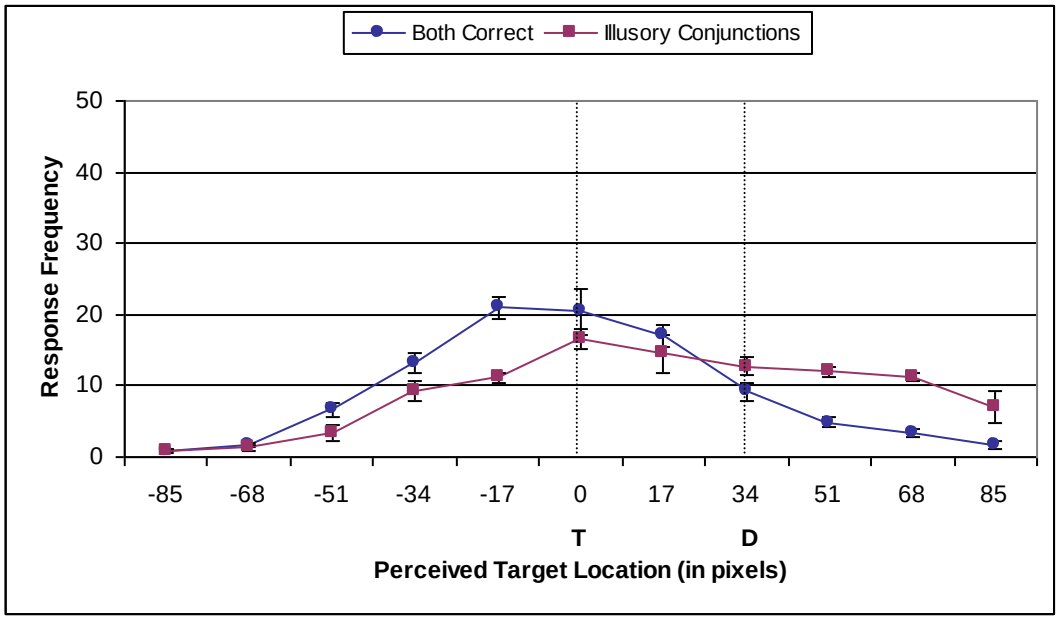

Figure 2.4a: The percentage frequency for both correct and illusory conjunction (target letter correct/distractor colour) response for the near condition shown as the distance in pixels from the actual location of the target. T represents the target position (0 pixels) and D represents the distractor position (34 pixels). Error bars = +/- 1 standard error.

A repeated measures ANOVA revealed a non significant overall effect for distance ($F(1,7) = 0.90$, $p>.05$), indicating that the mean perceived locations were very similar for all response categories, whether the target letter and colour were adjacent or separated by one intervening letter. Further analysis using a series of 2-tailed planned comparisons with Bonferroni correction (giving an adjusted significance level of 0.004) matched each response category with the actual target position of 0.00 pixels for both conditions. The Kolmogorov-Smirnov test for normality showed that all response categories in both conditions were normally distributed except for *incorrect letter/distractor colour* category in the *near* condition for which a nonparametric test was performed (Wilcoxon-Mann-Whitney *T*). Figures 2.4a/b show the perceived location of *both correct* and illusory conjunction responses for the *near* and *far* conditions.

For the *near* condition, there were adjusted non significant differences between the perceived and actual target location for *incorrect letter/correct colour* responses ($t(7) = -0.39$, $p>.004$) and *incorrect letter/colour incorrect* ($t(7) = 3.46$, $p>.004$). For the remaining three response groups, the perceived and target location differed significantly (*letter correct/distractor colour*, $t(7) = 9.29$, $p<.004$; *letter correct/colour incorrect*, $t(7) = 12.47$, $p<.004$; and *incorrect letter/distractor colour* $T(8) = -2.51$, $p <.004$ respectively).

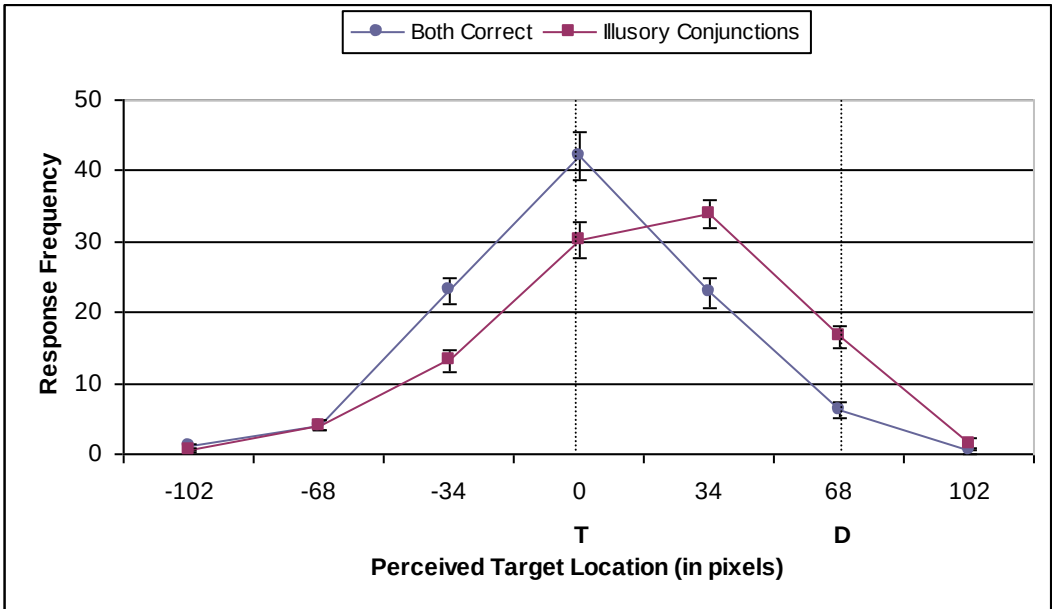

Figure 2.4b: The percentage frequency for both correct and illusory conjunction (target letter correct/distractor colour) responses for the far condition shown as the distance in pixels from the actual location of the target. T represents the target position (0 pixels) and D represents the distractor position (68 pixels). Error bars = +/- 1 standard error.

Far condition results showed a similar pattern of significance with one exception: the perceived and actual location of *letter correct/colour incorrect* were not significant

($t(7) = 2.96$, $p>.004$). The perceived and actual location of *incorrect letter/correct colour* and *incorrect letter/colour incorrect* both remained non significant ($t(7) = 0.30$ $p>.004$ and $t(7) = 1.12$, $p>.004$ respectively). For the remaining two response categories, the perceived and actual location of *letter correct/distractor colour* and *incorrect letter/distractor colour* were both highly significant ($t(7) = 7.66$, $p<.004$; $t(7) = 6.03$, $p<.004$ respectively).

Despite the similarity of results between the *near* and *far* conditions, it is apparent when examining the graphs, that while the *both correct* responses for the *far* condition were normally distributed around the actual target location, the distribution for *both correct* responses in the *near* condition was skewed away from the target in the opposite direction to the distractor. Nor is the perceived location of illusory conjunctions (*letter correct/distractor colour*) in the *near* condition centred round the midpoint despite a mean location of 22 pixels, which is reasonably close to the midpoint of 17 pixels. Rather, while there is a small linear decline of 3.8% from the target in the direction of the distractor, the perceived location of illusory conjunctions appear to be free-floating or located randomly between the target and the distractor. In the *far* condition, while the mean perceived location of illusory conjunction responses was 16 pixels, there appears to be a greater shift towards the midpoint between the target and distractor (34 pixels). This discrepancy may, in fact, reflect individual differences in the strategies used. To investigate this further graphs were plotted for each participant. Each represented the distribution for the *both correct* and *illusory conjunction* responses in both the *near* and *far* conditions and are shown in figures 2.5a to h.

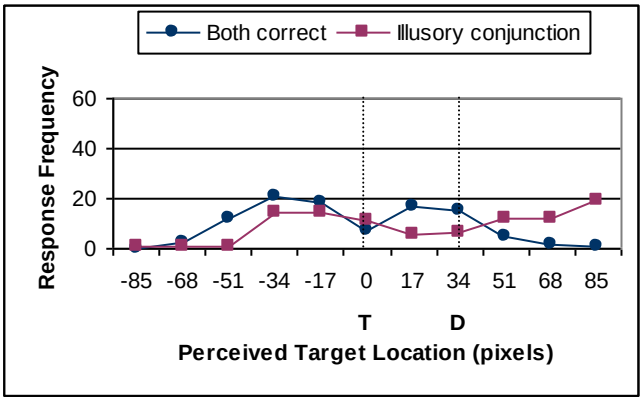

Figure 2.5a: participant 1 near condition

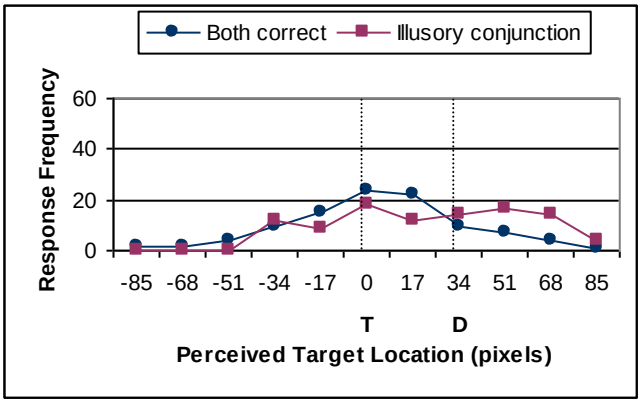

Figure 2.5b: participant 2 near condition

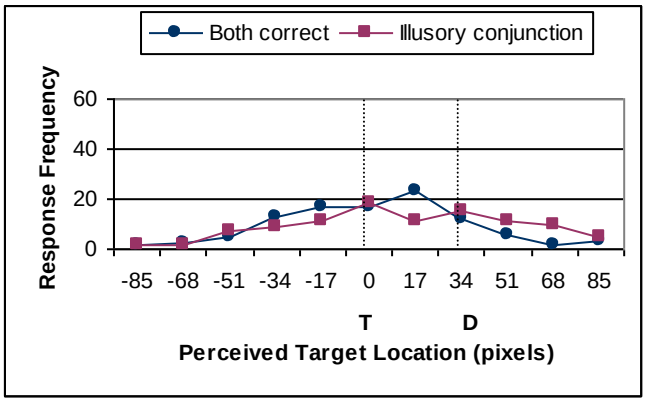

Figure 2.5c: participant 3 near condition

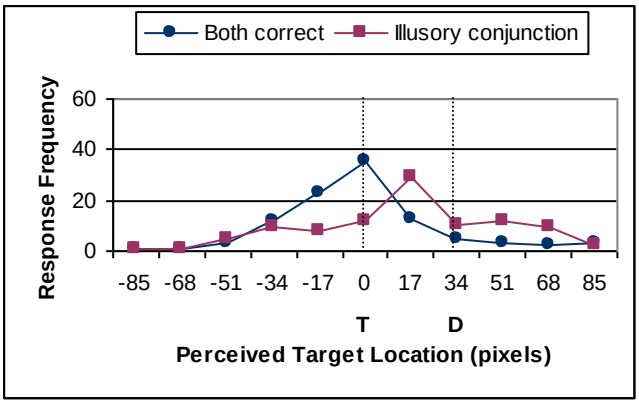

Figure 2.5d: participant 4 near condition

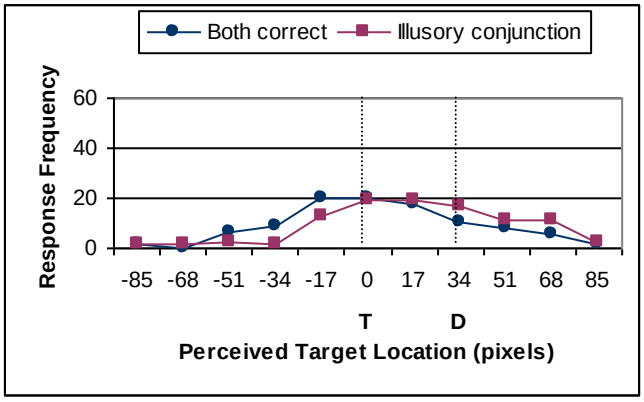

Figure 2.5e: participant 5 near condition

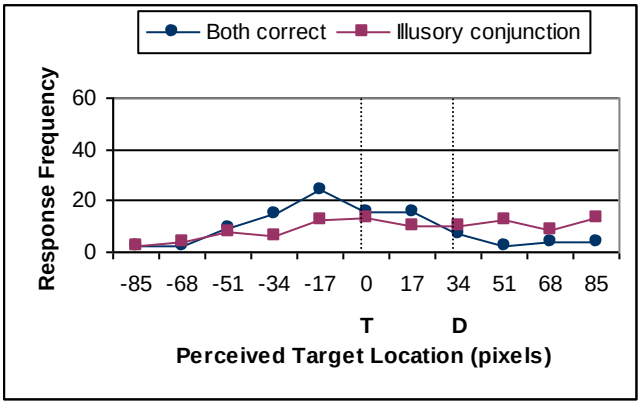

Figure 2.5f: participant 6 near condition

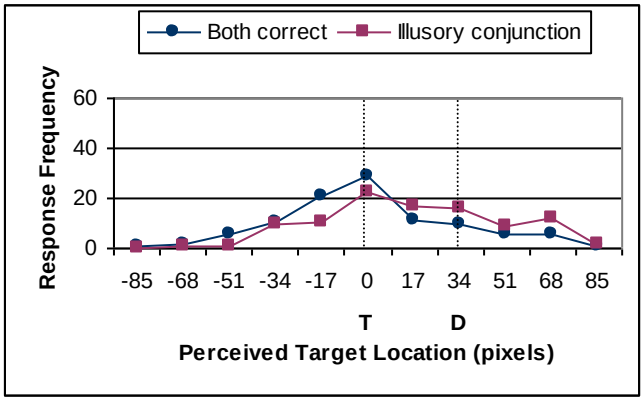

Figure 2.5g: participant 7 near condition

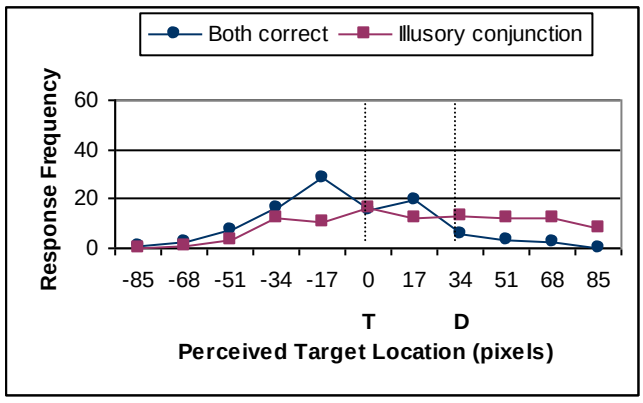

Figure 2.5h: participant 8 near condition

Inspection of the individual graphs in the *near* condition reveals that the majority of the participants (6 of 8) perceived the location of illusory conjunctions around the target with minimal bias toward the midpoint. Modes for each participant support this, with the exception of participant 1, whose response distribution is bimodal and centred at –34 pixels and –17 pixels, which is in the opposite direction from the distractor. Participant 5 shows a bimodal distribution centred round 0 pixels (target) and +17 pixels (midpoint) then slopes minimally towards the distractor. Only participant 4 reported a perceived location that was distributed around the midpoint. Therefore, the mean location

responses do not adequately reflect individual responses and to state that the perceived location of an illusory conjunction is centred round the midpoint appears somewhat premature.

Inspection of the individual graphs in the *far* condition (figures 2.6a to h) shows that half of the participants perceived the location of illusory conjunctions to be around the target with varying degrees of linear downward shift towards the distractor. For the remaining 4 participants, the perceived location was centred round the midpoint. This is particularly interesting because of the possible confound of the intervening non-target letter located at the same position as the perceived location of the illusory conjunction. Again, the mean perceived location of 16 pixels does not reflect individual responses.

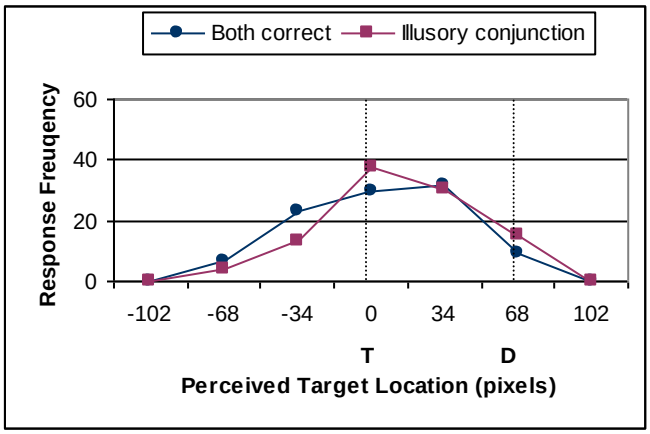

Figure 2.6a: participant 1 far condition

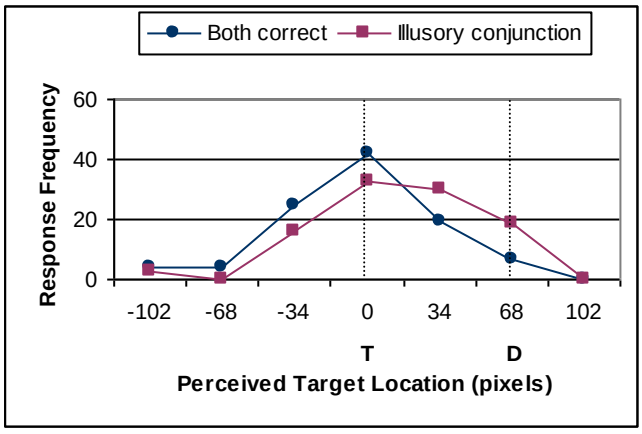

Figure 2.6b: participant 2 far condition

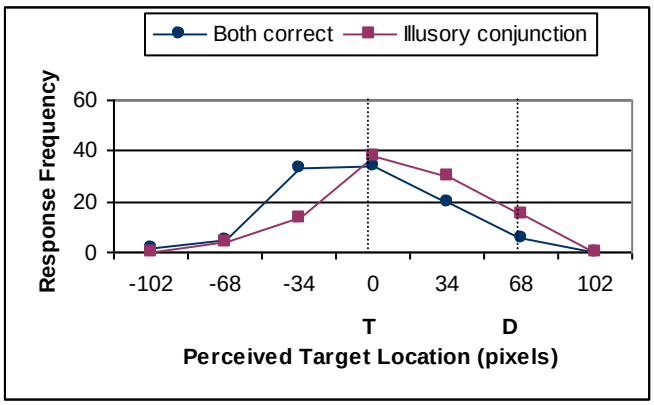

Figure 2.6c: participant 3 far condition

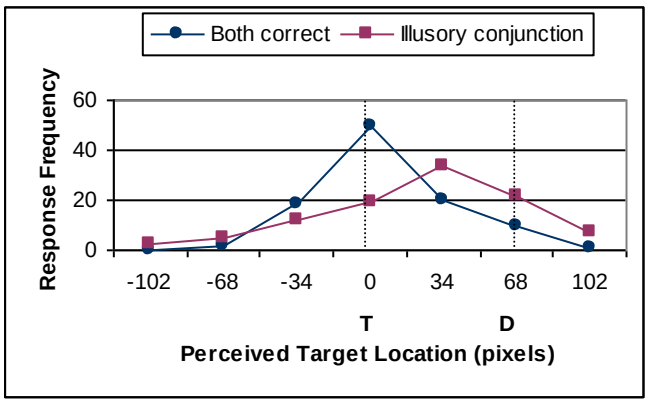

Figure 2.6d: participant 4 far condition

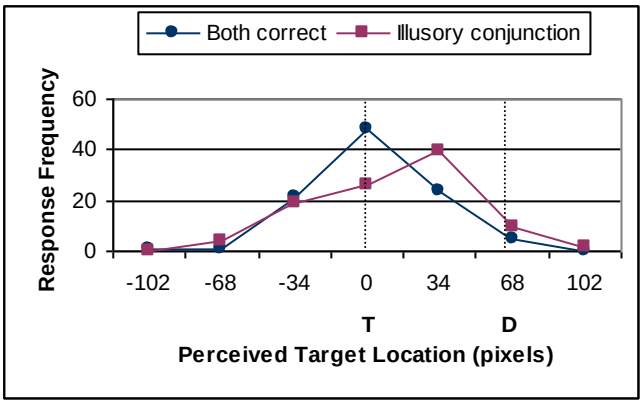

Figure 2.6e: participant 5 far condition

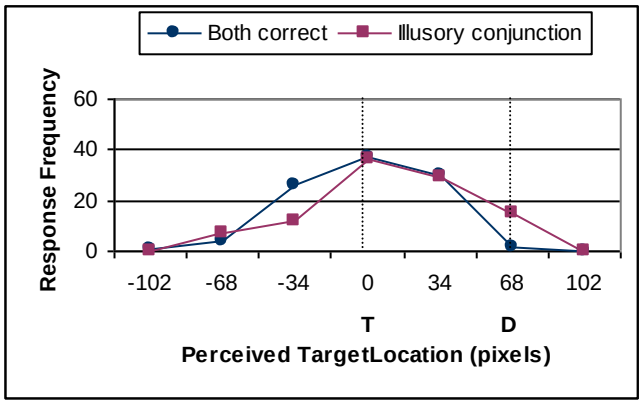

Figure 2.6f: participant 6 far condition

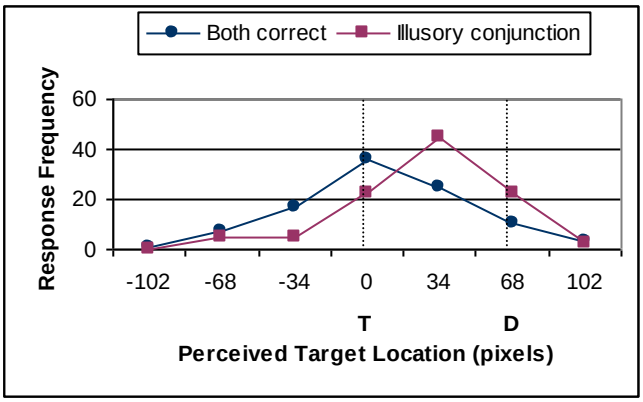

Figure 2.6g: participant 7 far condition

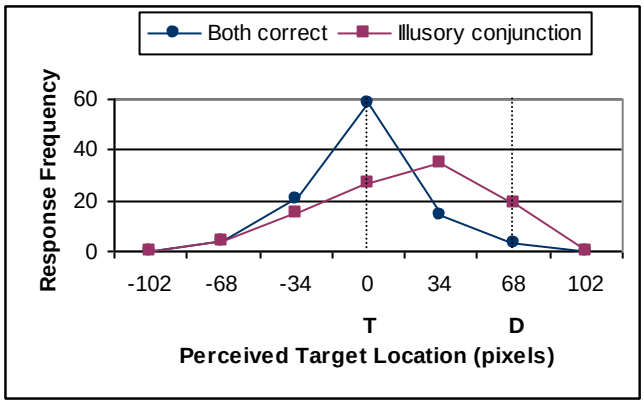

Figure 2.6h: participant 8 far condition

2.2.4 DISCUSSION

Results for experiment two showed that participants accurately identified both the colour and shape of the target letter on approximately 50% of all trials in both the *near* and *far* conditions. Illusory conjunctions were perceived on approximately 20% of trials for both conditions, with combined colour error responses amounting to almost 30% of all trials. The placement of stimuli further into parafoveal vision (from 2.01^{o} to 4.90^{o} of visual angle) dramatically increased the proportion of illusory conjunction responses as anticipated and provided far more data for analysis.

The proportion of *both correct* responses obtained at a stimulus interval of 52 msec lends further support to the notion that correct feature binding takes place early in the processing sequence (e.g. Cohen 1997; Tsal, 1989). However, while a majority of researchers using the illusory conjunction paradigm have argued that focused attention is not a requirement for integration to occur because a highly significant number of "unattended" features are both accurately perceived and bound, to suggest that feature integration can occur preattentively is a little premature as they do not discriminate between divided attention and preattention. As found for experiment one, the proportion

of correctly identified targets in the *near* condition that were also correctly located represented only 21% of the total. It is highly likely that this percentage related solely to trials in which the target was placed directly above or below the fixation point. This is again consistent with Cohen's (1997) proposal that feature binding occurs early but that only coarse (directional) location information is available when attention is widely distributed (e.g. Prinzmetal *et al*, 1998; Treisman, 1993; Tsal & Baraket, 2005; Tsal & Meiran, 1993).

However, contrary to expectations, no adjacency effect was found. This could indicate that the intervening letter in the far condition did not have a confounding effect on location results, particularly as the intervening letter was not in a primary colour. However, it is more probable that this was due to the increased visual angle for stimuli presentation. Several researchers have found that it is not just a feature from an adjacent object that can be misperceived as a target feature but any feature from objects that crowd round a target (Andriessen & Bouma, 1976; Bouma, 1970; Chung *et al*, 2001; Pelli *et al*, 2004; Toet & Levi, 1992; Wilkinson *et al*, 1997).

To determine what proportion of illusory conjunction responses could be attributed to guessing, confidence ratings for both the *near* and *far* conditions were examined. When confident responses as a mean proportion of *both correct* and *letter correct/distractor colour* responses were analysed, they indicated that a significant proportion of *both correct* and illusory conjunction responses were confident (76% and 68% respectively for the *near* condition, and 75% and 62% respectively for the *far* condition). This would suggest that both the correct target and illusory conjunctions were perceived with a similar amount of confidence, indicating that on the majority of trials, illusory conjunctions may be considered to be real perceptual phenomena although a proportion were indicative of guessing.

However, it is possible that *letter correct/colour incorrect* responses do not give a true reflection of *colour incorrect* responses. For example, this category probably contains a number of illusory bindings involving a non-target colour that was placed on the opposite side of the target to that of the distractor colour. Indeed, several participants complained that the colour they perceived was not given as a response option. In particular participants reported seeing the colour purple, a designated non-target colour and turquoise, a colour not used in the experiment. In regard to seeing purple, if this was occurring in the *far* trials where there was an intervening coloured letter placed between the target and the distractor, it would also suggest that this colour was not being ignored

as could be expected and may very well account for why a similar number of illusory conjunctions were found for both conditions. However, the perception of turquoise would suggest that two adjacent salient colours were being bound (blue and green).

The assumption that illusory conjunctions occur only as a result of confusing the designated distractor colour with the target colour does not allow for the possibility that an illusory conjunction can be made between the target shape and a non-target colour (green, orange, purple, grey or pink). However, no response colours were offered other than the three possible target and distractor colours (red, blue or yellow). This assumption is consistent with Treisman's (1991) proposal that within dimension features can be divided between primary features and secondary features (in this case colour) and that only the primary features can be identified preattentively. Primary features are those that are not a creation of two or more within-dimension colours such as red, blue, green and yellow. Secondary colours are a combination of two or more primary colours. For example, purple is comprised of red and blue, orange is comprised of red and yellow and turquoise is comprised of blue and green. If this is indeed the case, then participants should not have been able to perceive either purple or turquoise in the present experiment but would have been expected to perceive green (for which in practice no reports were made). However, Buchanan-Smith & Heeley (1993), using orientation, demonstrated that small deviations from the vertical (8^o tilt) can be easily detected when attention is distributed across the visual field and not merely the primary orientations of vertical and horizontal. This calls into question Treisman's (1991) proposal that only primary features can be identified preattentively and will be further investigated in chapter four.

The mean perceived location responses for both illusory conjunctions and letter correct colour errors in which the incorrect or distractor colour was chosen for the *near* condition showed some statistical structure, with each showing a systematic shift away from the actual target position in the direction of the distractor. This is contrary to the expectation of the *unitary* rule that colour errors are perceived round the actual location of the correctly identified feature, although there was an extremely high variance found for colour error responses indicating that these were perceived in random locations. In fact, all response categories showed a high degree of variance, including *both correct* responses. This may be an indication that individual features are perceived to be located anywhere within the attentional window as suggested by *FIT*. However, the statistical structure found for the mean perceived location of illusory conjunctions in the *near* condition, giving a mean of +22 pixels, was close to the midpoint between the target letter

and distractor colour (17 pixels). This finding could be seen as being at odds with the result that proximity showed no effect (indicating that there is no dissociation between feature detection and feature binding). For the *far* condition, the mean location of illusory conjunctions was perceived approximately +16 pixels from the target, almost midway between the target and the intervening letter. This indicates that illusory objects are perceived closer to the target than either the midpoint (34 pixels) or distractor (68 pixels) positions. It would appear that the intervening letter was not confounding the perceived location of the illusory object. Rather, it suggests that the correctly identified letter was the source of the perceived location but with a bias of approximately 23% of the interletter distance between the target and distractor. This represents 89% of the target width and is somewhat less than half that found by Tsal & Baraket (2005). Using a display consisting of a single coloured letter, they showed that even when attention is widely distributed (across 4^{o} of visual angle), a bias towards a fixation point of up to 200% of target width is apparent. As the results for the *far* condition are more indicative of a single source with bias, it is reasonable to suppose that this may also be true for the *near* condition. Indeed, with the experimental design used, it is impossible to distinguish between the aggregate model, in which the perceived location of an illusory conjunction is at the midpoint between the two contributing features (17 pixels) and a bias model where the bias accounts for 100% of target width (17 pixels).

However, the graphical data (figures 2.4a and b) show a somewhat different picture. For the *near* condition, while some structure can be seen in the small linear decline of the perceived location of illusory conjunctions moving from the target in the direction of the distractor, this decline is extremely shallow (3.8%) and while not strictly a rectangular distribution, is extremely close and more reflective of the free-floating model of Treisman & Gelade (1980). However, why this would have occurred when attention is distributed across the visual field is not clear. According to *FIT*, it is only before attention is focused or if attention is directed elsewhere that features should be free-floating in relation to one another (Treisman 1993, 2006). In the *far* condition, while the slope between the target and midpoint is extremely shallow (3.71%), the slope between the midpoint and the distractor is steep (17.43%) and is more indicative of the aggregate model.

To investigate the above results further, individual data were examined and graphs plotted. For the *near* condition, no consistent pattern emerges: only one participant conforms to the aggregate model and only two conform to the free-floating model. Of the

remaining five participants, while two showed a binomial distribution, three showed a distribution centred round the target. However, while no one current model is prevalent, five of the eight showed that location information was sourced from a single feature.

When examining the *both correct* responses, only two participants show the expected peak around the actual target position, although four show a similar distribution to the illusory conjunction responses but with three showing an approximate 18 pixel shift to the left and one an 18 pixel shift to the right. The remaining two participants show distributions that did not follow those of their illusory conjunction responses. Therefore, for the *near* condition, neither the individual mean perceived location nor the graphical data showed much consistency, with percentage responses falling randomly between the target and distractor and the majority of graphical distributions (5 of 8) indicating that location information is obtained from a single feature.

For the *far* condition, the graphical data reveal two distinct patterns for illusory conjunction responses. Four of the eight participants perceived the location around the actual target position but with varying degrees of linear downward slope towards the distractor. The remaining participants perceived the location to be centred round the midpoint between the target and the distractor. For *both correct* responses, the majority of participants (6 of 8) perceived the location of illusory conjunctions round the target position (0 pixels).

Looking at each participant individually has shown that averaging the data across participants neither takes account of individual differences, nor does it identify the different strategies used. Indeed, there is some suggestion that participants do not average the location information from both features that produce the illusory object as proposed by the *aggregate* model (Hazeltine *et al,* 1997). Instead, they use the location information from a single contributing feature as suggested by the second *WTA* model. As it stands, it is extremely difficult to distinguish between the two models. However, it is known that bias towards a fixation point increases in short-term memory (Werner & Diedrichsen, 2002). Therefore, adding a condition which extends the interval between the offset of the stimulus and onset of the response screen should determine whether the perceived location of illusory conjunction remains centred round the midpoint or moves further towards the fixation point. Experiment three addresses the problem by extending the design to include a delayed-response condition.

2.3 EXPERIMENT 3

2.3.1 INTRODUCTION

In experiments one and two, the mean location of illusory conjunction responses in the adjacent (*near*) condition was perceived to be close to the midpoint between the target and distractor (18 and 22 pixels in experiments one and two). While these could be construed as being close to the midpoint, individual plots indicated that the constant error is not a true reflection of the perceived location of an illusory conjunction. In the *far* condition, which had an intervening nontarget, the mean location of illusory conjunction responses was perceived to be 11 pixels in experiment one and 16 pixels in experiment two. This is closer to the target than the intervening letter (34 pixels) and certainly nowhere near the midpoint between the target and the distractor (also 34 pixels). Thus, overall these results are not consistent with the s*patial averaging* rule put forward by Ashby *et al* (1996) in which a real or illusory conjunction will be perceived in a location that is the spatial average of all contributing features. Rather, they may be more indicative of the *unitary* rule (Tsal and Lavie, 1988) and with the bias associated with the model of Tsal & Baraket (2005). This would suggest that while a feature error would be perceived around the veridical position of its respective source, a bias would also be observed.

It has been shown that briefly presented peripheral targets are remembered as being closer to the fovea than is actually the case (e.g. Huttenlocher, *et al*, 1991; Kerzel, 2002; Laeng, *et al*, 1998; Mateeff & Gourevich, 1983; Nelson & Chaiklin, 1980; O'Regan, 1984; van der Heijden *et al*, 1999). Werner & Diedrichsen (2002) have also found such bias when delays between the offset of the stimulus and response were as little as 50 msec. The bias then increased linearly with the delay. In their experiments three and four, they used a visual discrimination task in which a white dot was initially presented between two landmarks (small circles) on a black background for 200 msec. This was followed by a high intensity mask for intervals ranging from 50 to 400 msec. The initial stimulus was then represented for a further 200 msec with the dot either in the same location or shifted by 4.1 pixels. Participants were required to indicate whether or not the position of the dot relative to the landmarks had changed. They found that a spatial distortion was apparent at intervals as short as 50 msec but was dependent on the presence of the landmark.

Using a dual task paradigm with manual localisation (experiment one), Tsal & Baraket (2005) investigated whether reducing attentional resources would result in a loss

of location precision. First, a fixation cross was presented for 1.5 sec at the centre of the monitor. This was followed by a cue comprised of a small open circle presented for 50 msec at one of five locations depending on whether attention was focused or distributed. A 1 sec blank screen followed for either 20 or 70 msec. The target was comprised of a letter, randomly selected from A, E Q, W or Z and coloured brown. This was visible for 50 msec and presented either centrally or randomly within an imaginary square, each side being 7.8^{o} of visual angle. Participants were required to first localise the target by touching the screen with a marker then verbally identify it. The dispersion of location responses was greater along the radial than the diagonal axis. Further, the dispersion in the distributed attention condition (0.50^{o} centre and 0.64^{o} periphery) was only slightly greater than in the focused attention condition (0.44^{o} and 60^{o} respectively). Close examination of their results indicate that this bias represents approximately 1.5 to 2 target widths. Even when attentional resources were divided between two concurrent tasks with peripherally presented stimuli (experiment two), location responses were not random but represented a mean bias of approximately 2 target widths. Taken together, these experiments would suggest that a bias towards the fovea would not only be apparent at a delay of 50 msec but that such bias would represent between 150% and 200% of the target width depending on the position of stimulus in the visual field.

In the *far* condition for both experiments one and two of this thesis, the perceived location of the illusory conjunction represented less than one target width in both instances and for the *near* condition, it represented approximately one target width. However, while the results for the *far* condition were more indicative of a single source with bias, it was impossible to distinguish between the aggregate model, in which the mean location of an illusory conjunction is perceived at the midpoint between the two contributing features (17 pixels) and a bias model where the bias accounts for approximately 100% of target width (17 pixels) in the *near* condition.

Werner & Diedrichsen (2002) investigated the role of short-term memory on the perceived location of a simple object (dot). To allow manipulation of the internal orientation of the stimulus independent of the observer (allocentric space), displays consisted of two horizontally aligned landmark objects (o) and one target (●). In one condition, the landmarks objects were always presented 4.67^{o} apart from each other, in the second condition the landmarks were shifted both horizontally and vertically by a random amount but always within 3.7^{o}. The target was located at a random point between the two landmarks and was visible for 1.5 sec. In experiment one this was followed by a

blank screen for 2 sec after which the landmarks reappeared together with the cursor. Participants were required to reproduce the location of the target by clicking the mouse cursor. A systematic distortion in the perceived location of the target occurred that was consistent across participants. Subsequent experiments varied the mask presentation by delays of up to 800 msec and showed that the horizontal distribution of location responses increased linearly with delay.

The mean perceived location results from experiments one and two may be due to a similar bias, especially if the four non-target letters are acting as landmark objects. If remembered objects are perceived with a systematic bias, then increasing the delay between the offset of the stimulus display and response screen should result in a corresponding increase in displacement of the perceived target location across participants. However, if this is not the case and the mean perceived location responses remain centred around the midpoint between the target and the distractor, then it is more likely that the displacement is due to *spatial averaging*.

It should be noted however, that all three experiments reported here were conducted before issues relating to foveal bias were identified, therefore detailed information as to the relationship of the target to the fixation point was not available for analysis.

2.3.2 METHOD

2.3.2.1 DESIGN

To determine whether a systematic bias was being observed with the non-target letters acting as landmark objects, experiment three was identical to experiment two with two exceptions. First, because participants had complained that they were unable to see yellow, a change to green for one of the target colours was made. This resulted in an additional non-target colour having to be added (turquoise) to replace green. Second, a time interval was added with two levels, short delay (*sd*) in which the white noise mask was visible for 52 msec as for both previous experiments and long delay (*ld*), where the mask was visible for 2 secs. Both apparatus and materials remained identical to those used for experiment one and two.

2.3.2.2 PARTICIPANTS

There were sixteen participants, eight of whom had completed experiment two and a further eight who had not. All of which were members of Sussex University whose occupations ranged from senior research fellow to administration. There were eight

males and eight females with ages ranging from 22 to 55 years. All participants had normal or corrected to normal visual acuity. Payment for participation was made as follows: £10 for taking part plus a bonus payment for responding correctly to both the identification and location of the target stimuli, calculated as follows: for target identification accuracy, every correct identification over 50%, generated 1p; for target location accuracy, each 0.01 under 1.00 generated 2p.

2.3.2.3 STIMULI

The only alterations to the stimulus strings related to colour which was changed to accommodate participants' complaints that they found it difficult to detect yellow letters in the stimulus array. Therefore green replaced yellow as a target colour and turquoise replaced green as a non-target colour. This resulted in the following colour series: 1) orange, grey, turquoise, purple and pink; 2) turquoise, pink, grey, orange and purple; 3) purple, orange, turquoise, pink and grey and 4) pink, turquoise, orange, purple, and grey. The additional CIE (Commission Internationale de l'Eclairage) co-ordinates for green are: x = 0.37, y = 0.56, luminance = 14.76; and turquoise: x = 0.27, y = 0.33, luminance = 8.98.

2.3.2.4 PROCEDURE

The procedure for experiment three was identical to that for experiments one and two with one exception. On 50% of trials, the white noise mask was visible for 52 msec as before but on the other 50% of trials, this was increased to 2 sec. Each experimental trial therefore proceeded as follows: first, a fixation cross appeared in the centre of the screen for 500ms followed by the stimulus display that appeared for 52 to 156 msec. This was followed by either a 52 msec or 2 sec blank screen. Next, a row of location boxes appeared along the same horizontal axis as the stimulus.

2.3.3 RESULTS

2.3.3.1 OBJECT IDENTIFICATION

There were six possible response types for *distance* (*near* trials in which the distractor colour was adjacent to the target letter; and *far* in which the distractor colour was separated by one intervening letter). *Interval* comprised two delays (*short delay (sd)* where the SOA was 52 msecs and *long delay (ld)* where the SOA was 2 secs). Table 2.8 records the overall percentage means for each response category in all four conditions.

Condition		Target Letter Correct			Target Letter Incorrect		
		Colour Correct	**Distractor Colour**	**Colour Incorrect**	**Colour Correct**	**Distractor Colour**	**Colour Incorrect**
Near	SD	52.54 (10.58)	19.80 (5.27)	7.25 (2.80)	8.99 (4.44)	8.17 (4.60)	3.26 (2.20)
	LD	51.51 (10.94)	20.36 (4.28)	8.80 (2.63)	7.13 (3.84)	7.85 (4.41)	4.63 (2.84)
Far	SD	53.22 (15.38)	17.87 (6.25)	6.95 (3.96)	10.28 (6.38)	8.21 (4.25)	3.417 (3.32)
	LD	54.40 (12.27)	17.41 (4.21)	9.31 (3.34)	7.70 (6.01)	8.03 (3.67)	3.15 (2.37)

Table 2.8: Percentage mean (and standard deviation) of recorded identification responses for both conditions (near and far; short delay and long delay).

The significant main effect of interletter distance ($F(1,15) = 13.36$, $p<0.05$), suggested that distance strongly influenced whether participants were able to correctly identify the target, make illusory bindings or make feature errors. However, this was not reflected in the interaction between distance on the number of responses made for each of the six identification categories ($F(2.84, 42.64) = 2.61$, $p>0.05$). Nor did proximity have an appreciable effect on the number of illusory bindings made and this was confirmed by pairwise comparisons with Bonferroni correction (giving an adjusted significance level of 0.025) for both the *sd* condition ($t(15)=1.21$, $p>0.025$ and the *ld* condition ($t(15)=2.32$, $p>0.025$ although the latter was close to significance ($p=0.032$).

The duration between the short and long delay also had no significant overall effect ($F(1,15)=0.53$, $p>0.05$), nor was there an overall interaction between delay and the type of response made ($F(2.48, 37.14)$, $p>0.05$). This would indicate that a delay of 2 sec did not affect the number of correct responses but rather provided a similar number of responses in each category to those obtained for the short delay of 52 msec.

Confidence ratings were only provided by seven of the sixteen participants, so these were not analysed further.

2.3.3.2 OBJECT LOCATION

Normalisation of raw scores was again automatically computed by subtracting the response location from the target location giving a $\pm$ result in pixels. Negative values were given for response locations that were in the opposite direction to the distractor, positive values when the response locations were in the same direction as the distractor. Data were analysed as the pixel dispersal from the centre of the target (0 pixels). In the *near* condition, the distractor was approximately 34 pixels from the target and approximately 68 pixels from the target in the *far* condition, with an intervening letter placed at 34 pixels. Mean location responses are detailed in table 2.9.

Condition		Target Letter Correct			Target Letter Incorrect		
		Colour Correct	**Distractor Colour**	**Colour Incorrect**	**Colour Correct**	**Distractor Colour**	**Colour incorrect**
Near	SD	-6.00 (5.17)	10.27 (7.80)	-10.60 (12.61)	-7.67 (7.69)	6.67 (14.26)	4.80 (23.47)
	LD	0.87 (14.26)	8.80 (5.87)	-4.67 (12.15)	2.40 (20.21)	10.13 (12.74)	-6.80 (30.00)
Far	SD	9.27 (6.96)	42.67 (11.14)	17.93 (26.13)	13.53 (13.79)	47.73 (25.63)	27.67 (30.21)
	LD	7.93 (7.12)	36.27 (13.77)	24.20 (24.72)	24.67 (16.59)	42.00 (14.64)	37.93 (36.87)

Table 2.9: The mean (and standard deviation) of perceived location for each of the six response categories for both distance (near and far) and time (short delay and long delay) conditions.

While a repeated measures ANOVA revealed a significant main effect of distance (*near* or *far*) on where the location of the object was perceived to be ($F(1,14) = 239.13$, $p<0.01$), this was not the case for the time condition (*short delay* or *long delay*), ($F(1,14) = 1.16$, $p>0.05$). This would suggest that while distance affected the perceived location of an object, the difference in delay between the offset of the stimulus and the onset of the response screen did not.

However, a more detailed investigation of each response category revealed that for *both correct* responses in all conditions (*near sd, far sd, near ld* and *far ld*), the mean perceived location was recorded within the width of the target (18 pixels). In the *near* condition, the mean location for the remaining response categories (*letter correct/distractor colour; letter correct/colour incorrect; incorrect letter/correct colour; incorrect letter/colour incorrect; and incorrect letter/distractor colour*) was perceived either on or within 2 pixels of the target, regardless of whether the time delay between the offset of the stimulus and onset of the response screen was short or long. This indicated that both illusory conjunctions and incorrect responses, rather than being perceived round their respective source, were perceived close to the veridical position of the target letter.

Of the remaining five response categories for the *far* condition, whether the time delay was short or long, results were more equivocal. *Letter correct/colour incorrect; incorrect letter/correct colour; and incorrect letter/colour incorrect* responses indicated that the perceived location was reasonably close to the target but shifted in the direction of the distractor (approximately 22 pixels). *Incorrect letter/distractor colour* responses showed a clear shift away from the target (approximately 45 pixels) and were perceived closer to the distractor. Illusory conjunctions were perceived near to the midpoint between the target and the distractor (approximately 39 pixels), as were long delay *incorrect letter/colour incorrect* responses.

These findings were subjected to a series of 2-tailed planned comparisons with Bonferroni correction (giving an adjusted significance level of 0.002) and matched each of the six response categories for both distance (*near* and *far*) and time (*short delay* and *long delay*) with the absolute target position. The Kolmogorov-Smirnov test for normality showed that all of the response categories in both the distance and time conditions were normally distributed. Pairwise comparisons for *both correct* responses in all conditions showed that while there were non-significant difference for *near ld* ($t(15) = 0.16$, $p>.002$), the remaining three conditions (*near sd, far sd,* and *far ld*) were all significant ($t(15) = -4.52$, $p<0.002$; ($t(15) = 4.92$, $p<.002$; ($t(15) = 4.65$, $p<.002$). Illusory conjunction responses in all conditions also showed a highly significant shift away from the target ($t(15) = 5.20$, $p<0.002$; ($t(15) = 5.66$, $p<0.002$; ($t(15) = 15.25$, $p<0.002$ and ($t(15) = 10.82$, $p<0.002$ respectively).

All remaining response categories in the *near* condition, whether the time delay was short (*near sd*) or long (*near ld*), revealed that perceived location responses were not significantly removed from the actual target location for: *letter correct/colour incorrect* ($t(15) = -2.97$, $p>.002$ and ($t(15) = -1.60$, $p>.002$); *letter incorrect/colour incorrect* ($t(15) = 0.0.79$, $p>.002$ and ($t(15) = -0.79$, $p>.002$); and *incorrect letter/distractor colour* ($t(15) = 1.69$, $p>.002$ and ($t(15) = 3.09$, $p>.002$). However, while the perceived location for *incorrect letter/correct colour* responses for *near ld* were not significantly removed from the actual target location ($t(15) = 0.30$, $p>.002$), the perceived location responses for *near sd* showed a highly significant shift away from the target ($t(15) = -3.68$, $p =.002$).

For the remaining response categories in the *far* condition, all but *letter correct/colour incorrect* responses in the *short delay* condition ($t(15) = 2.85$, $p>.002$) showed a significant shift away from the target: l*etter correct/colour incorrect* responses in the *ld* ($t(15) = 4.08$, $p<.002$); *incorrect letter/correct colour* ($t(15) = 4.18$, $p<.002$ and $t(15) = 6.13$, $p<.002$); *incorrect letter/distractor colour* ($t(15) = 7.16$, $p<.002$ and ($t(15) = 11.01$, $p<.002$); and *incorrect letter/colour incorrect* ($t(15) = 3.88$, $p<.002$ and ($t(15) = 4.37$, $p<.002$).

These results are generally consistent with the above observations that for the *near* conditions (*sd* and *ld*), the perceived location for all response categories was within 2 pixels of the width of the target letter. For the *far* conditions however, all response categories except for *both correct* responses, which were perceived within the target width, showed a distinct bias towards the distractor. For *letter correct/colour incorrect, incorrect letter/correct colour, and* short delay *incorrect letter/colour incorrect* responses

the perceived location was reasonably close to the target but shifted approximately 22 pixels in the direction of the distractor. *Incorrect letter/distractor colour* responses showed a clear bias of approximately 27 pixels from the distractor towards the target. Illusory conjunctions were perceived on the intervening letter, midway between the target and the distractor, as were long delay *incorrect letter/colour incorrect* responses (approximately 39 pixels).

However, of particular interest in this experiment was whether the perceived location of illusory conjunction responses would show an increase in the bias away from the target when a 2 sec delay was imposed between the offset of the target and the onset of the response screen. The mean perceived locations of illusory conjunctions for time in the *near* condition showed little difference between the short to the long delay conditions (1.47 pixels towards the target). This can be seen in figure 2.7a.

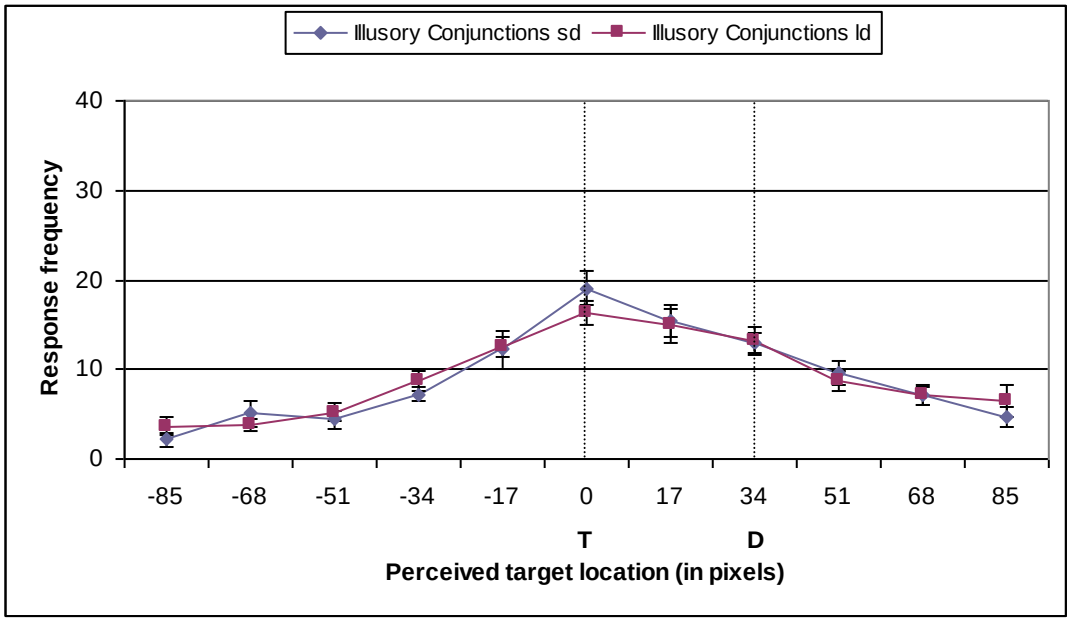

Figure 2.7a: The percentage frequency of responses showing the effect of delay (short and long) on the perceived location of illusory conjunctions shown as the distance in pixels from the actual location of the target in the near condition. T represents the target position (0 pixels) and D represents the distractor position (34 pixels). Error bars = +/- 1 standard error.

For the *far* condition, mean responses do not adequately reflect response distributions. The mean perceived location for illusory conjunction responses showed a shift in the opposite direction to that expected from the short to the long delay, albeit again with only a small bias of 6.4 pixels (figure 2.7b). While there was a sharp increase in the perceived location at the midpoint (34 pixels) from those recorded at the target location with a smaller decline towards the distractor for the short delay, responses are

more evenly spread between the target and distractor for the long delay. Therefore, while there was a clear increase in bias away from the target, albeit for the short delay in the *far* condition, the lack of an increase in bias for delay in the *near* condition may not be a true reflection of individual responses. Indeed, the large variable error found further indicates that individual responses reflect different strategies. To determine whether this was the case, individual graphs were plotted showing the position of *near* illusory conjunction responses for both the short delay and long delay conditions (figures 2.8 a to p).

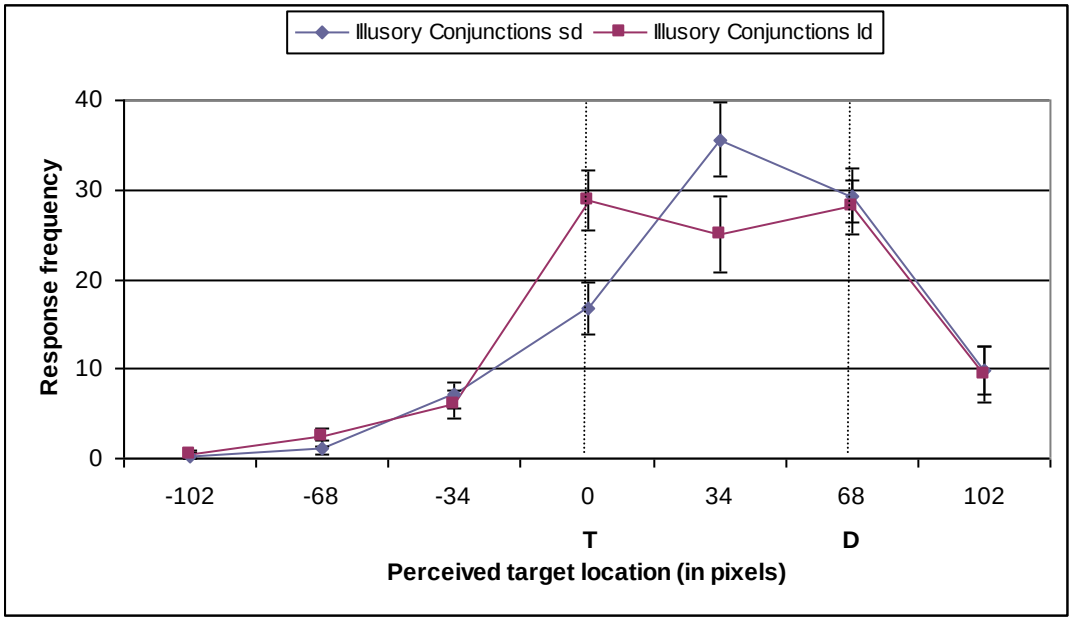

***Figure 2.7b:* The percentage frequency of responses showing the effect of delay (short and long) on the perceived location of illusory conjunctions as the distance in pixels from the actual location of the target in the far condition. T represents the target position (0 pixels) and D represents the distractor position (68 pixels). Error bars = +/- 1 standard error.**

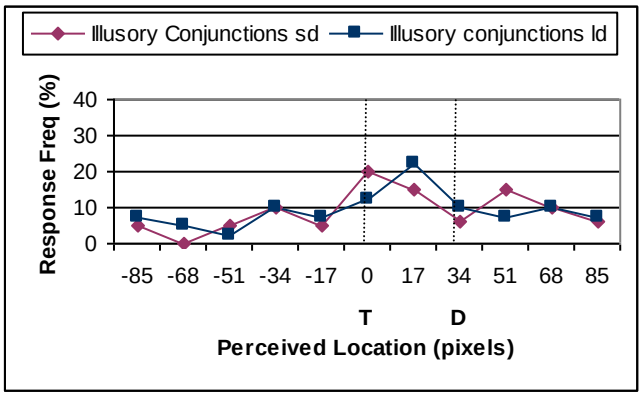

Figure 2.8a: participant 1 near condition

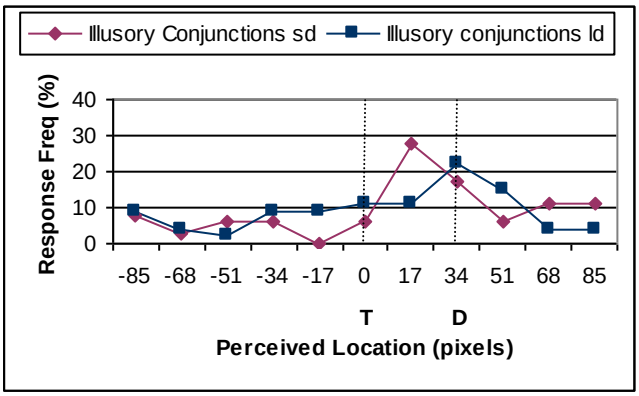

Figure 2.8b: participant 2 near condition

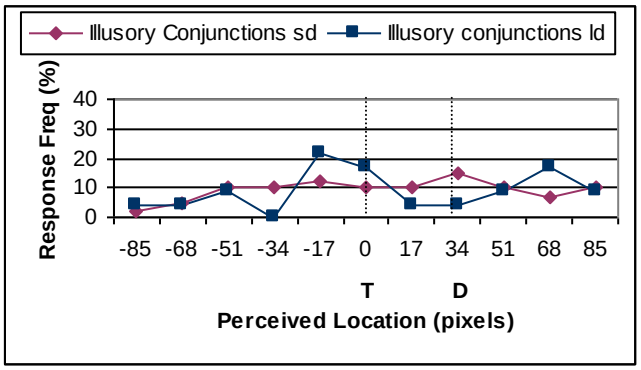

Figure 2.8c: participant 3 near condition

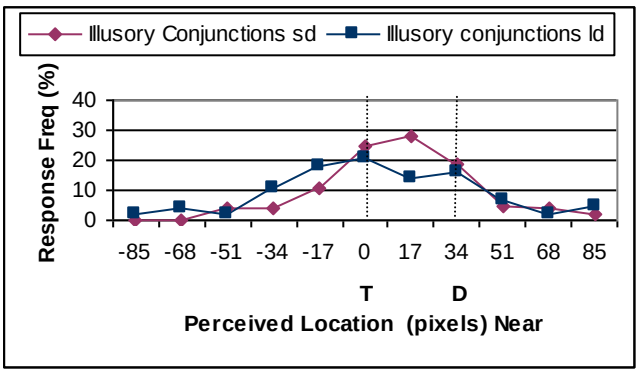

Figure 2.8d: participant 4 near condition

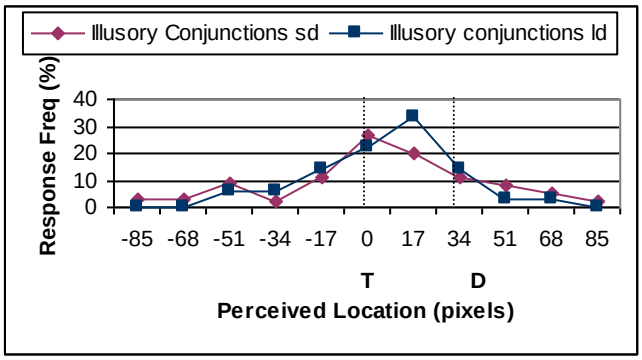

Figure 2.8e: participant 5 near condition

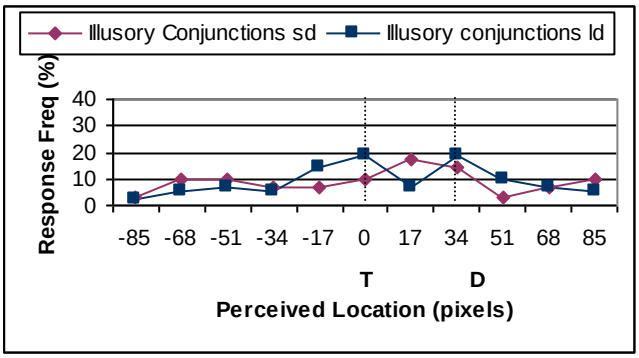

Figure 2.8f: participant 6 near condition

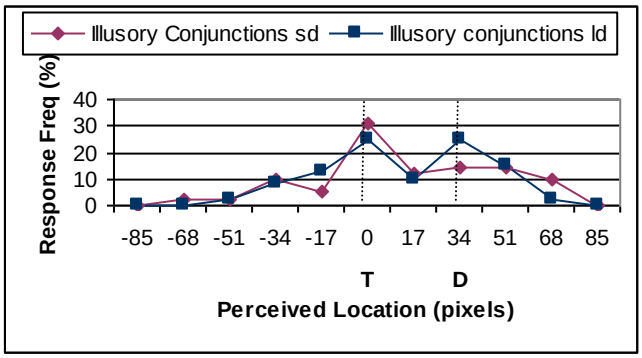

Figure 2.8g: participant 7 near condition

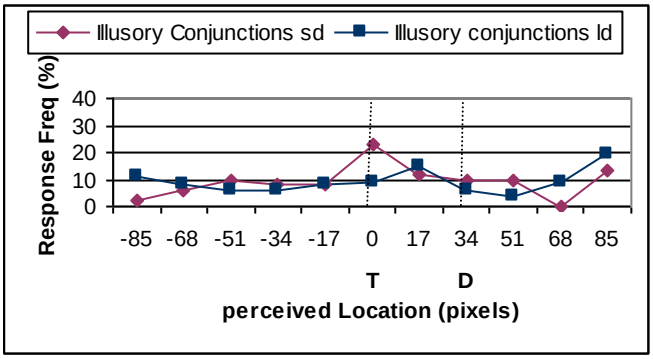

Figure 2.8h: participant 8 near condition

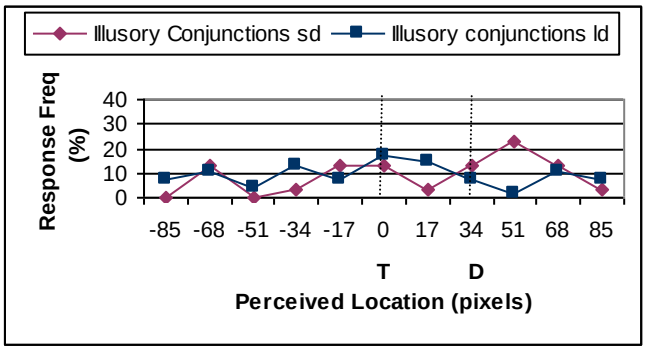

Figure 2.8i: participant 9 near condition

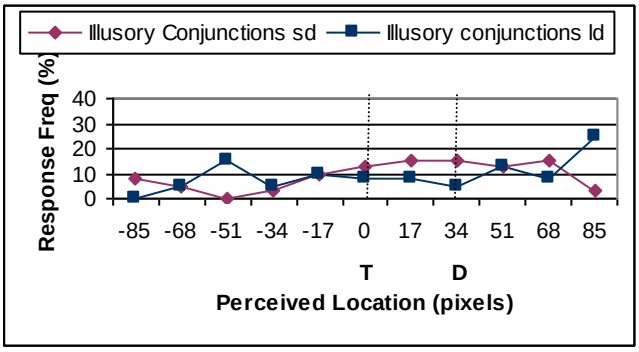

Figure 2.8j: participant 10 near condition

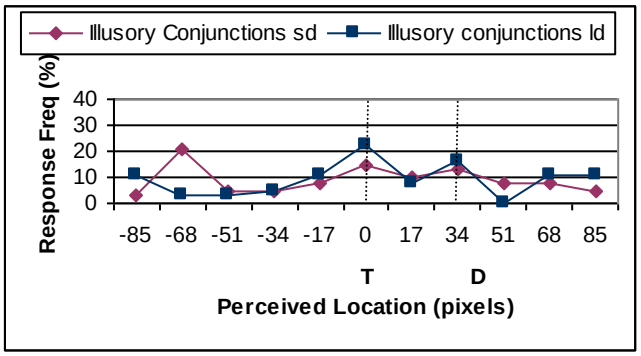

Figure 2.8k: participant 11 near condition

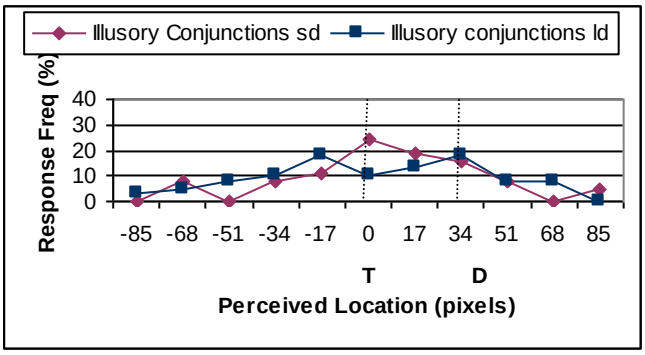

Figure 2.8l: participant 12 near condition

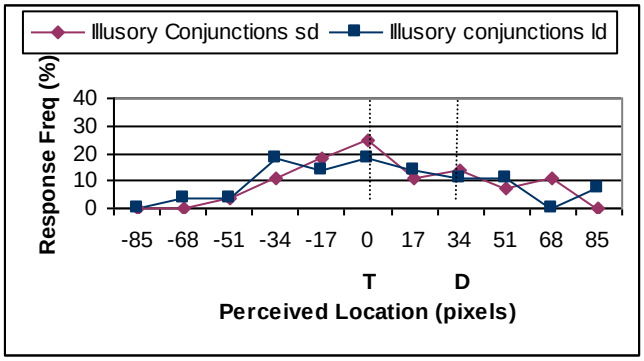

Figure 2.8m: participant 13 near condition

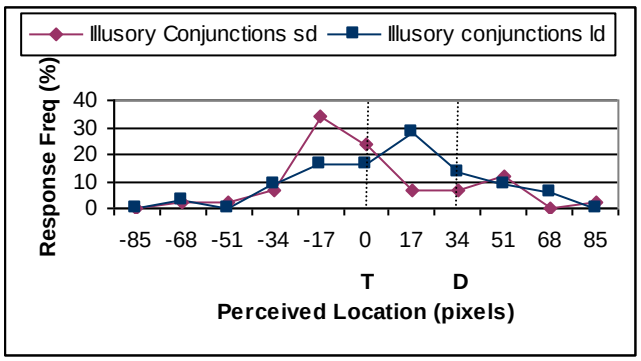

Figure 2.8n: participant 14 near condition

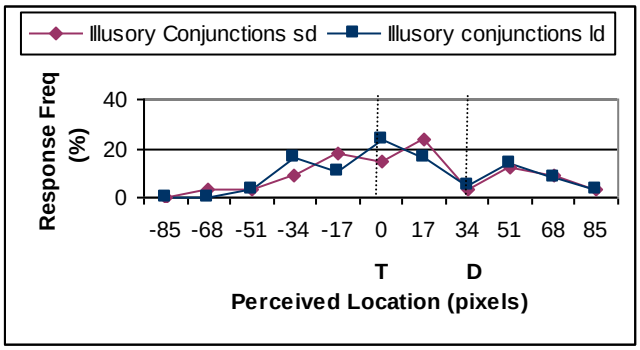

Figure 2.8o: participant 15 near condition

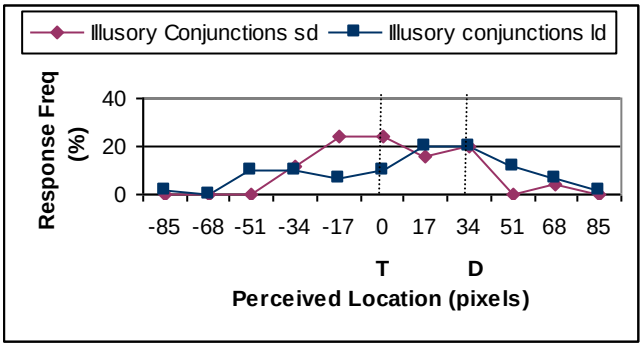

Figure 2.8p: participant 16 near condition

Inspection of each individual graph reveals that averaging data across participants was not a true reflection of the perceived location of illusory conjunction responses by individual participants. Only two participants showed no bias at all. Of the remaining fourteen participants, six showed a clear increase in bias for the long delayed condition in the direction of the distractor by approximately one target width; one showed a bias in the same direction but extending to two target widths. Similarly, two participants showed a bias moving in the opposite direction by one target width and two in the same direction but with two target widths. Three participants showed a bias from the target to that of the mixture model: one showed a bias of approximately 17 pixels, half being away from the target in the direction of the distractor and half in the opposite direction; one showed the

same response pattern but the bias increased to approximately 34 pixels; and one where the increase towards the distractor increased to approximately 34 pixels. Individual graphs for illusory conjunction responses for both *far sd* and *far ld* are detailed in figures 2.9a to p.

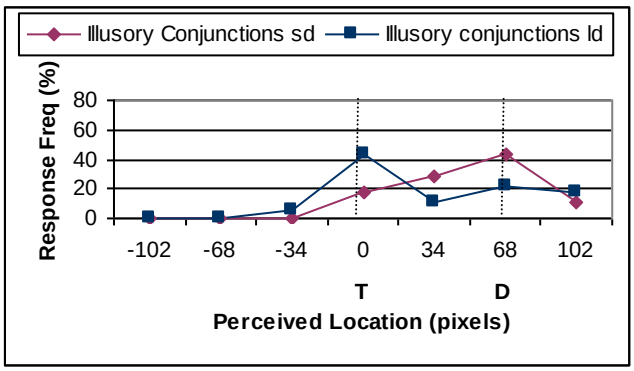

Figure 2.9a: participant 1 far condition

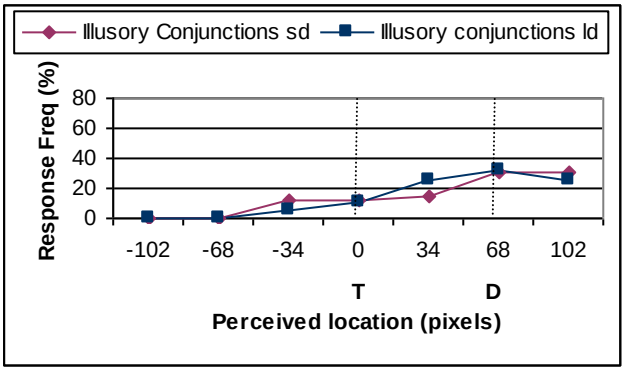

Figure 2.9b: participant 2 far condition

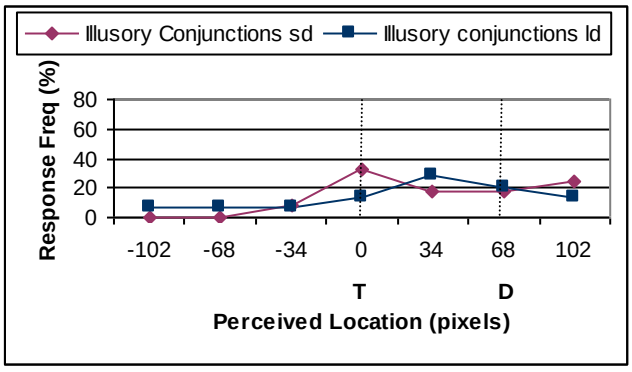

Figure 2.9c: participant 3 far condition

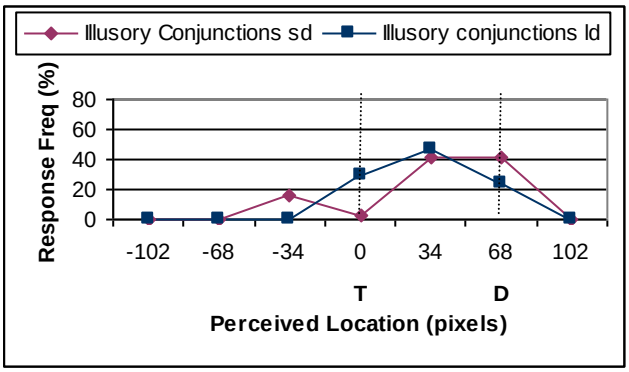

Figure 2.9d: participant 4 far condition

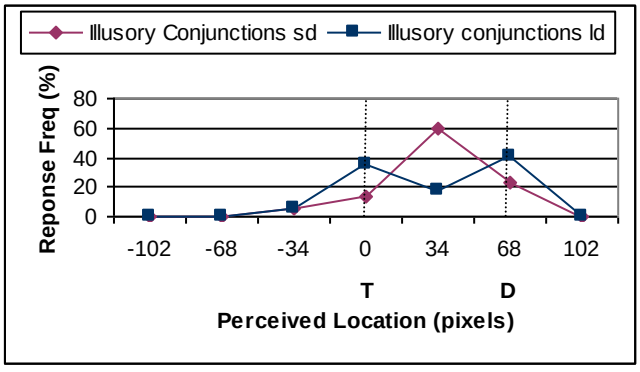

Figure 2.9e participant 5 far condition

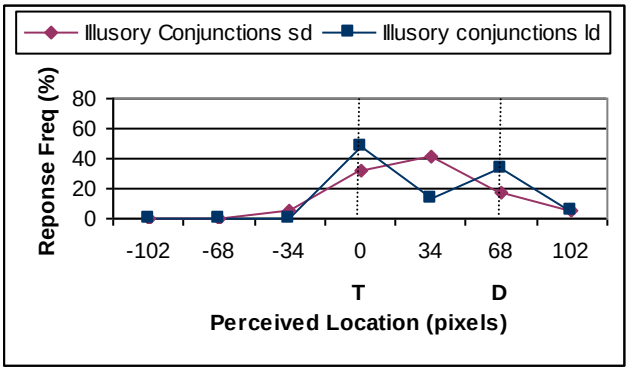

Figure 2.9f: participant 6 far condition

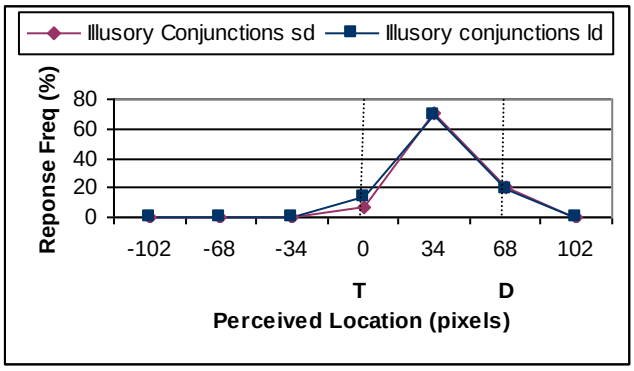

Figure 2.9g: participant 7 far condition

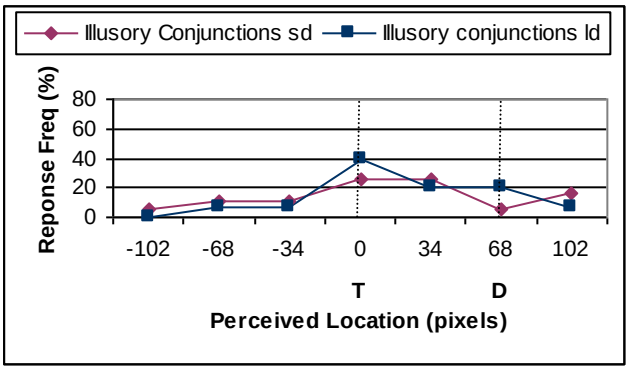

Figure 2.9h: participant 8 far condition

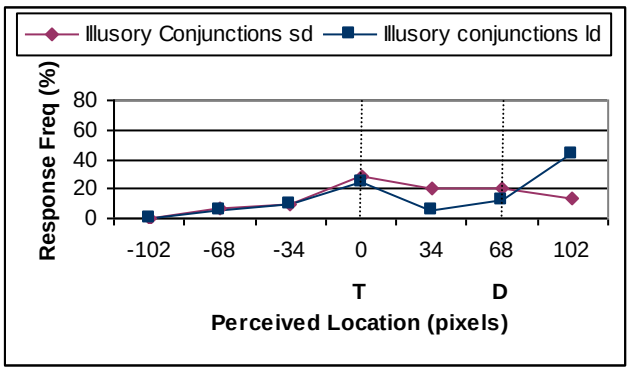

Figure 2.9i: participant 9 far condition

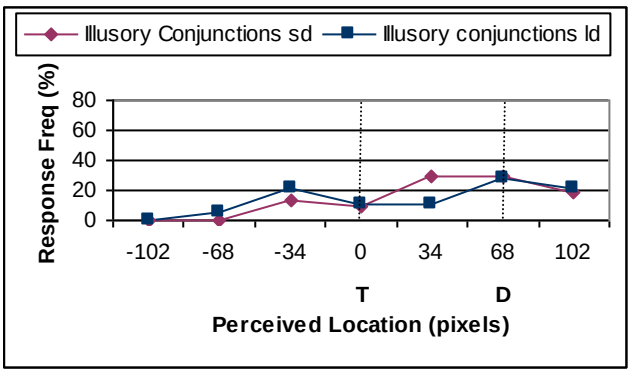

Figure 2.9j: participant 10 far condition

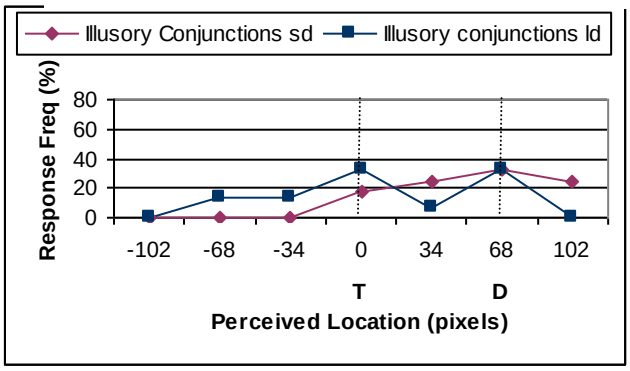

Figure 2.9k: participant 11 far condition

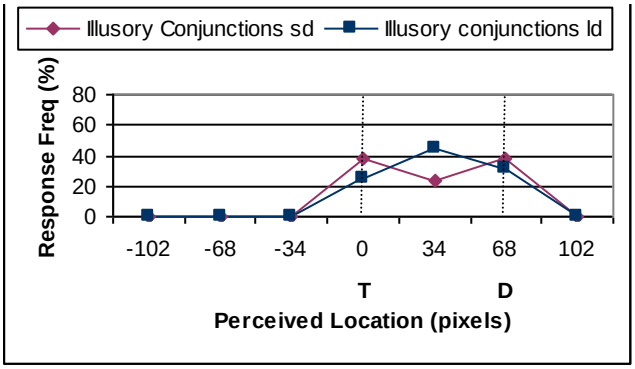

Figure 2.9l: participant 12 far condition

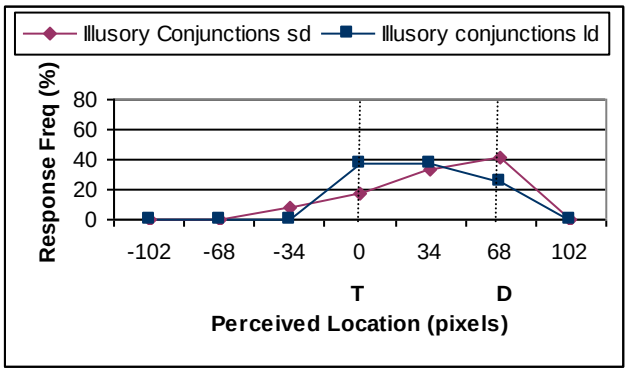

Figure 2.9m: participant 13 far condition

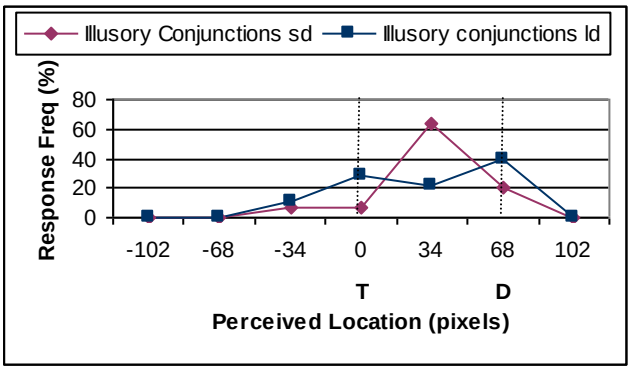

Figure 2.9n: participant 14 far condition

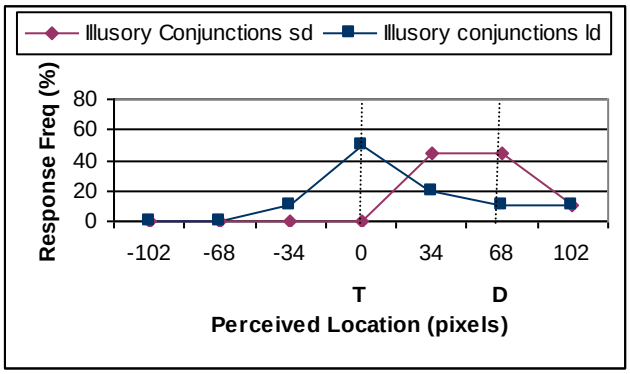

Figure 2.9o: participant 15 far condition

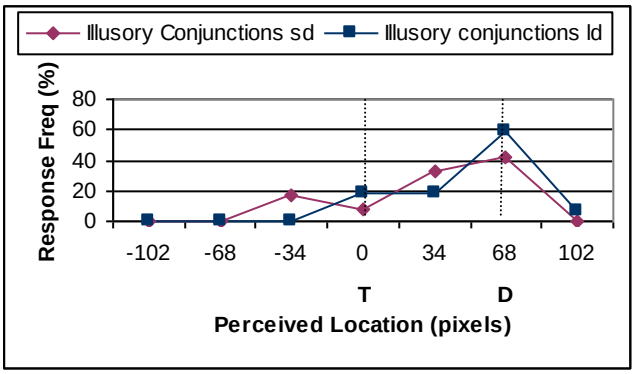

Figure 2.9p: participant 16 far condition

The situation changed somewhat for the *far* condition. While four participants showed no shift at all, six showed a distinct bias of two target widths (34 pixels). Three of these were in the direction of the distractor, two in the opposite direction, and one from the midpoint to a mixture model. Of the remaining six, two showed a shift of four target widths, both in the opposite direction of the distractor, two averaged one target width, one in each direction and two averaged three target widths, both in the opposite direction of the distractor. Again, averaging data across participants provided a pattern that did not reflect individual strategies.

2.3.4 DISCUSSION

Target identification accuracy was comparable to that found for experiment two. *Both correct* responses, in which both the target colour and shape were correctly identified, represented approximately 53% of all trials in both the distance and time delay conditions. Illusory conjunctions represented approximately 19% for both conditions while combined feature error responses, in which either colour or shape or both were incorrectly identified, amounted to almost 28% of all trials. Of the total correctly identified targets, only 29% were correctly located for the *near sd* condition and 30% for the *near ld* condition. This proportion rose to 51% for the *far sd* condition and 50% for the *far ld* condition. Therefore, while distance significantly affected the proportion of correctly identified targets that were also correctly located, time delay did not. Participants were equally accurate in identifying and locating a target when the delay between the offset of the stimulus display and onset of the response screen was increased to two seconds as when the delay was only 52 msec. However, it was not possible to determine whether such correctly located targets were as a result of their being close to

the fixation point due to the randomised positioning of the stimulus in the visual field. Nevertheless, these results are indicative of binding occurring early (Cohen, 1997) despite there only being coarse location information being available when attention is distributed across the visual field (e.g. Cohen & Ivry, 1991; Tsal & Baraket, 2005).

While an overall effect of distance was obtained, this was not reflected in the number of illusory conjunction responses found for both the *near* and *far* conditions, although it was close to significance for the long delay condition. However, the lack of an adjacency effect was not unexpected as Bouma's (1970) bound was again violated for 50% of all *near* trials but only 20% of *far* trials, suggesting that illusory conjunctions had a far greater likelihood of forming between the target and distractor on *far* trials than on *near* trials. One way to resolve this issue is by removing the intervening letter for the *far* condition and this issue will be directly addressed in a later experiment.

The proportion of illusory conjunction responses that could be deemed to be genuine perceptual phenomena was extremely low in this experiment. A significant proportion of all categories of responses for both the *distance* and *delay* conditions were rated as "confident". Therefore, it would be unsafe to attribute any of the illusory conjunction responses to genuine perceptual experiences.

The proportion of responses where both the target letter and colour were correctly perceived increased by approximately 4% in the equivalent *near* trials but it remained static for *far* trials. However, whether this increase was due to changing one of the target colours from yellow to green is unlikely. Had perceiving yellow been as difficult as indicated by some of the participants in experiment two, it would have been expected that a far greater increase in the proportion of both correct responses would have been apparent as yellow represented the target colour in 33% of all trials.

Considerable structure was again found for the mean perceived location of colour correct responses regardless of whether the correct or incorrect letter was chosen and whether the time delay was short or long. In every case, this was within the target area for all *near* condition responses. While similar results were found for both correct responses in the *far* condition, when the incorrect letter was perceived, the perceived location moved somewhat closer to the distractor although in neither case was this close to the midpoint. Similar structure was found for all colour error responses and letter incorrect/distractor colour responses which were perceived on or within one pixel of the target for all *near* trials. In the *far* condition the shift was further towards the distractor (approximately 21 pixels) for *letter correct/colour incorrect* but for both incorrect and letter

incorrect/distractor colour responses, the perceived location was on or reasonably close to the midpoint. However, it should be noted that there was an extremely high degree of variance for all such responses indicating that regardless of whether the correct letter was chosen or not, the locations were randomly perceived.

Illusory conjunction responses also conformed to expectations for the *near* but not the *far* condition. In the *near* condition the perceived location was on or extremely close to the target. However, for the *far* condition it was approximately located over the intervening letter and close to the midpoint between the target and distractor. These findings are the reverse of those found for experiments one and two. Further, an extremely high degree of variance in location responses was also found. This was comparable to that found for experiment one. The shift of the overall perceived location from the midpoint to the target for both *near* conditions was unlikely to be an artefact of the experimental design as this had not changed across the three experiments in any fundamental way. To investigate this reversal, individual graphs were examined for the short delay condition so that a comparison could be made across all three experiments. For the *near sd* condition, seven of the sixteen participants perceived the location of illusory conjunctions to be centred round the target, four round the midpoint and two round the distractor. Of the remaining three, one showed a shift away from the target in the opposite direction of the distractor, one showed a binomial distribution between the target and distractor and one a random distribution. Again no one strategy emerges. However, eleven of the sixteen graphs indicated that location information was sourced from a single feature.

For the *far sd* condition, the pattern of results showed an almost complete reversal, with the perceived location of illusory conjunctions being perceived round the target for two participants, five round the midpoint and seven round the distractor. Of the remaining two, one showed a binomial distribution between the target and distractor and one a random distribution. Again, the majority of participants show that the location information of an illusory conjunction is provided by a single feature.

Examination of only *confident* location responses showed that participants perceived the location of an object, whether it was the actual target or illusory, closer to the actual target location when confident for all *near* and *far* conditions. These results would indicate that in *both correct* and *illusory conjunction* responses, the source of the location information is the shape of the target. While this would be expected for the *both correct* responses, it would have been the colour that should have provided the location

information for the *illusory conjunction* responses and not the shape. These results would suggest that it is solely the feature that is correctly identified that provides the location information.

Of particular interest in this experiment was whether an increase in bias would be perceived when the delay between the offset of the stimulus to the onset of the response screen was increased from 52 msec to 2 sec. Averaging data across participants indicated that this was not the case. The overall mean for the *near* conditions showed that illusory conjunctions are perceived over the target regardless of whether the time delay was short or long. For the *far* conditions however, there was a shift from the midpoint between the target and distractor to the random model, indicating a bias of anywhere up to two target widths. These results appear to be at odds with those of Werner & Diedrichsen (2002), who showed that bias increases linearly with time delay.

However, examination of individual graphs again revealed a somewhat different picture. For the *near* conditions, in all but two cases, bias had increased with the delay between the offset of the stimulus and the onset of the response screen although the size of the bias varied. While nine revealed a bias of 0.5 of a target width (9 pixels), for the remaining five, this increased to 1.5 target widths (27 pixels). For the *far* condition, four participants failed to show any bias at all. Of the remaining twelve, two showed a bias of approximately 0.5 of a target width, six a bias of 1.5 target widths, two showed an average bias of 2.5 target widths and the remaining two, a bias of 3 target widths.

However, while it would be expected that bias would increase with the distance between objects (Hubbard & Ruppel, 2000), the degree of variability between individuals is not easily explained. Nevertheless, these results show that in the majority, if not in all cases, the location of an illusory conjunction is sourced from a single feature with variable amounts of bias and not, as Hazeltine *et al*, (1997) suggested, sourced from an aggregate of location information from each contributing feature.

2.4 INTERIM DISCUSSION

While the correct identification of the target was recorded on a high percentage of trials, indicating that cross-dimension feature integration occurs early in the processing cycle (Cohen, 1997), there were far fewer trials in which target stimuli were both correctly identified and located. This would indicate that in general, only coarse (directional) location information is available when attention is widely distributed (e.g. Prinzmetal *et al*, 1998; Treisman, 1993; Tsal & Baraket, 2005; Tsal & Meiran, 1993). In all three experiments, the inability to accurately locate the target could be directly related

to differing positions of the stimulus in the visual field. This would be consistent with correct reporting being inversely related to distance as suggested by both Ballard (1986) and Eurich & Schwegler (1997). Unfortunately, it was not possible to determine this because a record was not made of the relevant information. This omission is rectified in experiment nine.

The possibility that *colour incorrect* responses are not an accurate reflection of true feature errors was indicated when several participants complained that the colour they perceived was not given as a response option. This was despite the fact that participants were told that the target colours would be red, blue or yellow. It would suggest that on occasion, exogenous or stimulus driven selection is superseding endogenous or goal driven selection in these experiments. Thus, participants appear unable to ignore non-target colours even when instructed to look for a unitary colour. While such stimulus driven capture has been found when colour was neither the defining feature nor a target attribute (Gibson & Yiang, 1998; Yantis, 1993), this was not the case for the experiments reported above. However, it has been observed when naïve participants are used (Turatto & Galfano, 2001). In the present studies, reported perceptions of two specific colours were noted: purple, which was designated a non-target colour and turquoise, which was not (for experiments one and two). If the perception of purple was occurring in the *far* trials, where there was an intervening coloured letter placed between the target and distractor, it may indicate that this colour was not being ignored as could be expected. Rather, it may account for why a similar proportion of illusory conjunctions were found for both conditions in experiments one and two. However, as turquoise was not used in either experiment one or two, the perception of turquoise would suggest that two adjacent primary colours are being bound (green, a non-target colour with blue, a target/distractor colour). Chapter three directly addresses this issue.

An adjacency effect was found in experiment one but not in experiments two or three. However, this difference can be accounted for by the positioning of the stimulus further into parafoveal vision for these experiments, allowing interference from both the distractor and intervening non-target items to occur with greater frequency. Several researchers have found that it is not just a feature from an adjacent object that can be misperceived as a target feature as suggested by Cohen & Ivry (1989) but any feature from objects that "crowd" round a target (Andriessen & Bouma, 1976; Bouma, 1970; Chung *et al*, 2001; Pelli *et al*, 2004; Toet & Levi, 1992; Wilkinson *et al*, 1997). Bouma

(1970) proposed that if the distance between objects is equal to or less than half the distance between the target and a central fixation point, then any feature from those objects can replace a target feature and cause an illusory conjunction. However, because no record was made in the present experiments of the actual position of the target in relation to fixation, it is not possible to determine on which trials Bouma's bound was violated. This issue will be addressed in experiment four.

All three experiments showed a somewhat confusing structure to the perceived location of illusory conjunctions with experiment three showing a reversal to that found for experiments one and two. The overall mean location of illusory conjunction responses in the adjacent *near* condition for experiments one and two were perceived to be close to the midpoint between the target and distractor. In the equivalent *near short delay* condition in experiment three, it was approximately two pixels from the edge of the target. This would indicate that both the *spatial averaging* and *unitary* rules provide the information required to locate an illusory object. Results for the *.far* condition, which had an intervening nontarget, were the same. The overall mean location of illusory conjunction responses in experiments one and two was perceived to be close to the target position. For experiment three, this moved to the midpoint and was located over the intervening letter.

When data for each participant was examined separately for experiments two and three, it was found that not only are both rules represented but also the *random* rule of *FIT*. This was compounded when the data indicated that for those participants who took part in both experiments, a high proportion used a different strategy for each experiment with only one participant showing any consistency across the two. It is difficult to account for such a high degree of variability found between participants unless each strategy relates to attentional allocation.

The overall lack of an increase in bias for the *near delayed* condition for experiment three was not born out by individual data. Fourteen of the sixteen participants showed a clear increase in bias. This approximated one item width for all but one participant where it increased to two item widths. However, in all three experiments, both overall and individual results included location information from all parts of the visual field and this must have provided a distorted picture and would have confused any clear pattern of responses. This would be particularly true if, as has been suggested, bias always moved in the direction of the fovea (e.g. Huttenlocher, *et al*, 1991; Kerzel, 2002; Laeng, *et al*, 1998; Mateeff & Gourevich, 1983; Nelson & Chaiklin, 1980; O'Regan,

1984; van der Heijden *et al*, 1999) or was influenced by the other salient object in the display as suggested by both Hubbard (1995) and Kerzel (2002). For example, it has been shown that briefly presented peripheral targets are remembered as being closer to the fovea than is actually the case (e.g. Huttenlocher, *et al*, 1991; Kerzel, 2002; Laeng, *et al*, 1998; Mateeff & Gourevich, 1983; Nelson & Chaiklin, 1980; O'Regan, 1984; van der Heijden *et al*, 1999). Werner & Diedrichsen (2002) have also found such bias when delays between the offset of the stimulus and response were as little as 50 msec. The bias then increased linearly with the delay but was dependent on the presence of the landmark.

From these experiments no clear picture emerges and it would appear that both the *spatial averaging* and *unitary* rules can underlie the perceived location of illusory conjunctions. However, not recording the position of the target in relation to fixation may have contributed to this inability to show a clear distinction and this methodological limitation will be addressed in experiment nine. This should make it possible to determine whether bias has any role to play in the perceived location of illusory conjunctions, whether features from different dimensions can be correctly bound but not located and whether the information from both contributing features conforms to the *spatial averaging* or *unitary* rule. However, the issues raised above regarding colour may have also had a direct bearing on participants' location responses. Therefore, the next series of experiments directly address questions of colour.

CHAPTER 3: THE PERCEPTION OF COLOUR

3.1 EXPERIMENT 4

3.1.1 INTRODUCTION

In their debriefing after experiments one and two, a significant number of participants stated that the colour of the target was perceived to be other than one of the three target/distractor colours (red, blue or yellow). In particular, several said that they had seen the colours purple and, to a lesser extent, turquoise. As purple was one of the non-target colours, it is likely that participants formed an illusory conjunction with this item rather than with the distractor colour, particularly if it was directly to the left of the target. Purple was adjacent to the target for 25% of *near* trials and 50% of *far* trials. Turquoise was not used in either experiment. These observations are particularly interesting for two reasons. Firstly, while it would be reasonable to suppose that *a priori* knowledge about the target colours (red, blue and yellow) would have prevented any other stimulus colours from being perceived, a suggestion made by both FIT and the Guided Search model (e.g. Treisman & Sato, 1991; Wolfe, 1994), the perception of colours other than those used for the target/distractor implies that *a priori* knowledge did not guide bottom-up processing of the stimulus. Secondly, it may be the case that purple was perceived when it was present in the display. It would also be reasonable to suppose that both purple and turquoise could have been perceived on those trials where either blue and red or blue and green formed part of the colour string, resulting in a within-dimension illusory conjunction. However, for experiments one and two, combining the colours of the blue and green used does not result in turquoise but in a different blue: + = . Therefore, it is difficult to see how such a within-dimension binding could occur and further investigation was warranted.

In real world settings, many incorrect feature conjunctions are ruled out by *a priori* knowledge. For example, we would not expect to see blue grass when in a park or people walking by with green skin! While *bottom-up* processing occurs automatically and without recourse to *top-down* constraints, several studies have shown that knowledge speeds perception (e.g. Biederman, 1972). To determine the extent of *a priori* knowledge in a laboratory setting, Treisman & Butler (see Treisman, 1986) used an illusory conjunction paradigm. Three coloured objects were presented for 200 msec, flanked on either side by two digits. This was followed by a mask that also contained a

cue to indicate which of the three objects was to be reported after the two digits. The crucial element of the experiment was whether the participants were told that the three central objects consisted of an orange triangle, a blue ellipse and a black ring or whether the same objects represented an orange carrot, a blue lake and a black tyre. They found that participants reported considerably more illusory conjunctions when objects were coloured geometric shapes than when presented with familiar coloured objects. However, a third group of participants who were presented with incorrect combinations of natural objects such as an orange tyre or blue banana did not make illusory conjunctions that matched their knowledge base. Rather, they were no more likely to see the carrot (triangle) as orange when another object in the display was orange than when no orange object was present. Treisman (1986) concluded that while *a priori* knowledge facilitates the efficient conjoining of individual features into a coherent object, it does not lead to the formation of illusory conjunctions in order to meet expectations. Similarly, other studies have also found that prior knowledge does influence performance but only when familiar objects are used (e.g. Prinzmetal & Mills-Wright, 1984; Prinzmetal *et al*, 1986). Therefore, while the individual features in experiments one and two were in themselves well known (T and X; red, blue and yellow), the association of a particular colour with a particular letter, such as a blue T does not constitute a familiar object indicating that *a priori* knowledge played no significant role in identification. If, as FIT proposes, illusory conjunctions arise at an early stage of visual processing that precedes any access to the knowledge base, then it is possible that colours other than those used for the target and distractor could be bound with the target letter. However, could a binary[7] non-target colour pop-out in a display containing a unitary[8] target and distractor?

It has also been well documented that featural pop-out only occurs in cross-dimensional conjunction searches if the individual features that make up the target are salient and comprised of elements not present in any of the distractors (e.g. Duncan & Humphreys, 1989, 1992; Nakayama & Silverman, 1986). Such parallel search is possible for a unique target when surrounded by up to nine distractors (Duncan, 1988; Smallman & Boynton, 1990; Wolfe, Yu, Stewart, Shorter, Freidman-Hill & Cave, 1990). For example, Duncan & Humphreys (1989) as part of their attentional

[7] A binary colour is one that is comprised of the elements of two unitary colours (such as violet). If the binary is intermediate, it is comprised of equal parts of the two unique colours (such as purple or orange).
[8] A unique colour is a colour that contains no perceptual similarity to another colour (such as red, blue, green or yellow).

engagement theory (AET) to explain visual search performance emphasised that the pattern of linearly increasing search times with set size was directly related to the similarity of the target to distractors and inversely related to the similarity of distractors to each other. Therefore, the difficulty in finding a target increases as the similarity of the target to the distractors increases (TD similarity) but decreases as the similarity between the distractors increases (DD similarity). Search will be fast and easy if either the TD similarity is low or the DD similarity is high regardless of the number of distractors in the display. However, as TD similarity increases or the DD similarity decreases, search becomes increasingly difficult. They further proposed that performance could be affected by the relationships between all designated targets and distractors within a given experiment, so that the more features from a stimulus array that are grouped together, the greater the tendency to select or reject them together making search easier. Using only colour differences with shape remaining constant, Moraglia, Maloney, Fekete, & Al-Basi, (1989) confirmed Duncan & Humphreys' (1989) prediction that the interaction between TD similarity and DD similarity produced large latency differences. They found that RT's dramatically increased when colour variations amongst distractors were high (DD similarity was low) and the target was similar to the distractors (TD similarity was high). When TD similarity was low, the effect of low DD similarity was minimal (see also Farmer & Taylor, 1980).

While search is more efficient when the unique feature is part of the target rather than part of a distractor, an intermediate binary colour such as purple, which is comprised of equal proportions of red and blue, may also pop-out in displays where either no red or no blue is present in any other item (Treisman & Gormican, 1988; Treisman & Souther, 1985). Treisman & Gormican (1988) looked at search asymmetry and found that search was also more efficient when looking for a binary colour embedded among unitary colours, such as a purple target among red distractors but considerably more difficult when the search was for a red target among purple distractors. They concluded that search for a target is efficient when it contains unique featural information. Thus, because a purple target is comprised of both red and blue, search for blue among distractors that are not blue will allow the search to be easy whereas search for a negative (search for an item that is not blue), such as for a red target among purple distractors will be difficult. They proposed that preattentive feature space is only coarsely coded and can be divided into only a few basic unitary features (e.g. red, blue, green and yellow; vertical, horizontal, left and right diagonals). Non-

standard or binary feature values that are close to the primaries in feature space are coded as the unitary value together with a signal noting a deviation. For example, violet would be signalled by activity in blue detectors together with a small amount of activity in the red detectors. In this way, detection of a target becomes easy when it generates a unique signal in a feature map. Thus, a violet target will pop-out among a field of blue distractors because it has a red component but a red target will not pop-out among violet distractors because red is present in both target and distractors (see also D'Zmura, 1991; Bauer, Jolicoeur & Cowan, 1996; Nagy & Sanchez, 1990; Treisman, 1985, 1991).

D'Zmura (1991), using visual search and CIE (Commission Internationale d'Eclairage[9]) colour space tested a wide range of colour stimuli that varied in hue, saturation and/or luminance and suggested that opponent process mechanisms[10] could be used to explain some pop-out effects (see figure 3.1). He found that when presented foveally, the colour mechanisms required for parallel search are sensitive enough to distinguish binary colours provided that target and distractor colours are linearly (widely) separated in colour space so that the target is comprised of an element not present in the distractors. For example, search was parallel for a yellow target among red and green distractors and for a red target among yellow and blue distractors. However, this was not the case when search was for an orange target among red and yellow distractors because orange is not linearly separable from red and yellow (i.e. orange is comprised of both red and yellow elements). However, linear separability only appears to hold when the colour differences are small (Bauer *et al*, 1996). As non-target heterogeneity had either been reduced or any bottom-up processing been eliminated, this would indicate that categorical colour information is activated in a top-down manner. For example, while search for a categorically unique *yellow* among *red* and *green* items is parallel and efficient, search for *yellow/green* among *orange* and *blue/green* is serial despite the distances in colour space being identical in both instances.

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[9] The CIE's colour space diagram represents an internationally agreed method of colour identification using perceptual and physiological measurements based on the additive mixing of light at mean luminance measured under average daylight.

[10] Opponent processes (Hering, 1905: translated by L.M. Hurvich and D. Jameson, 1965). The human visual system interprets information about colour by processing signals from cones and rods in an antagonistic manner. At the level of retinal ganglion cells, the trichromatic colour code is processed by neurons to respond to pairs of unitary colours with red opposing green and yellow opposing blue.

If differences between D'Zmura's (1991) experiments one and two are examined closely, the results can be explained more simply in terms of Duncan & Humphreys (1989) AET model. In experiment one, the distractors were lime and purple making them unique from the orange target in respect of green and blue and providing low DD similarity. This unique distractor information could have been used to reject them, allowing the target to pop-out. In experiment two, the yellow and red distractors were not unique in any way from the orange target (high T/D similarity) and so the target could only be detected by processing each item individually.

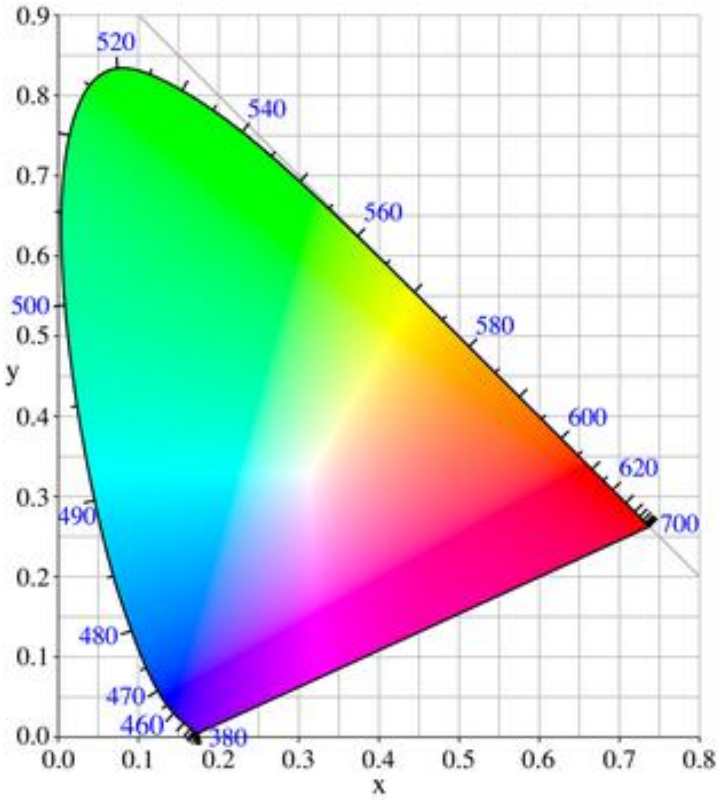


Figure 3.1: Diagram of CIE (Commission Internationale d'Eclairage) colour space (1931). The outer curved boundary is the spectral (or monochromatic) locus, with wavelengths shown in nanometers.

In experiments one and two of this thesis, all three of the target colours were unique or unitary colours. Of the non-target colours (green, orange, magenta, purple and grey) orange, magenta and purple were intermediate binary colours with grey being an equal mix of black and white. The remaining non-target colour, green, was also a unique colour but no participant reported seeing green when asked during the debriefing. While the similarity between green and any of the three target colours was low, Reijnen, Rich, Van Wert & Wolfe (2007) found that regardless of the effects of TD similarity, DD heterogeneity and linear separability, categorical colour plays an

important role in guiding attention in visual search. Thus, searching for a blue target among non-targets that are from different categories such as reds or greens is more efficient than when the non-targets are from the same colour category. However, if this was the case, then participants would not have been expected to report seeing turquoise either.

It can be seen that the similarity between the target, distractor and non-targets in experiments one and two is somewhat complex. While a distractor was always comprised of one of the two remaining target colours, three further non-targets were present in the display. Nevertheless, the target/distractor similarity was consistently low (red/blue, red/yellow or blue/yellow) and it would be expected that on those trials where the distractor was unique, while the target was comprised of elements present in the non-targets, an IC would be formed. However, while there is evidence to suggest that a binary colour such as purple can be easily found among heterogeneous non-targets or among blue non-targets, what evidence is there to indicate that when searching for a target that might be blue, a binary non-target colour such as purple would be perceived instead?

Under certain conditions pop-out can occur for within-dimension conjunctions. For example, Wolfe *et al* (1989) found parallel conjunction search for highly discriminable sizes, vertical & horizontal orientation, circle and cross shapes as well as for the colours red and green although Nagy & Sanchez, 1990 found that small differences between target and distractor colours are not processed in parallel but require serial search. Nothdurft (1993) suggested that salience is graded in that two salient objects can be compared, with one appearing to be more salient than the other. It is interesting to note that while Wolfe *et al* (1989) found that red and green were easily discriminable, this was not the case for red/blue or blue/green. However, this may well be due to the fact that red and green are opponent colours (see D'Zmura, 1991 above) whereas red/blue and blue/green are not (blue/yellow was not tested).

Indeed, Hinton (1981) had already suggested that unique within-dimension features are represented by different values in limited separate sets of detectors (for example: red, green, blue and yellow or vertical and horizontal). To correctly bind features from within the same dimension, such as red and blue to make purple, would require focused attention. While unitary features are coarse coded, binary within-dimension stimuli would not activate separate feature detectors nor would they pop-out from other items in the display. Small differences within a single dimension should not

activate separate feature detectors and so would not pop-out from the other items in the display. Thus, while a purple target would pop-out among either blue or red distractors it would not if placed within a field of blue and red distractors occupying the same location. These would require binding of both blue and red detectors.

However, it has been suggested that higher order mechanisms may be present that have spectral sensitivities matching each of the binary colours of orange, turquoise, purple and lime (D'Zmura, Krauskopf, & Lennie, 1987; Krauskopf, Williams & Heeley, 1982; Krauskopf, Williams, Mandler & Brown, 1986). For example, D'Zmura *et al* (1987), found bandwidths and spectral sensitivities of colour opponent mechanisms using heterochromatic noise masking techniques. Masking signals of intermediate colour (comprised of equal amounts of two unique colours such as orange) resulted in *off-frequency looking* analogous to that found in spatial vision (Pelli, 1980). Off-frequency looking relates to the early level of processing in which an observer's threshold should be the threshold of the most sensitive spatial frequency component or receptive field. However as high frequency noise greatly increases the thresholds of high (but not low) spatial frequencies, observers can look off-frequency or away from the spatial frequency component with the highest threshold to obtain a better signal-to-noise ratio (see Pelli, 1981). Thus, it is assumed that the observer uses whichever spatial frequency component is best for the task. D'Zmura *et al* (1987) suggested that such off-frequency looking showed the presence of detection mechanisms tuned to intermediate binary colours. However, while such results would suggest that purple can be perceived when searched for amongst unique colours, it is extremely unlikely that purple will be perceived when search was for a blue, red or yellow target.

Treisman (1991) argued that within-dimension pop-out would occur for a limited number of dimensional values which are coarse coded by the visual system. However, when within-dimension binding was required not only would search slopes be significantly higher but far more IC's would occur than for between-dimension binding. For example, in a search task, a blue vertical target embedded among pink vertical and blue left tilted bars required only that blue and vertical be bound. However, search for a target comprised of a left tilted violet bar among distractors that are left tilted turquoise bars and right tilted violet bars will require additional processing. For example, one distractor would activate the target conjunction of red and blue (violet) while the other would activate left and tilted (orientation). This would necessitate two within-dimension bindings followed by a between-dimension binding to obtain the target (the

violet left-tilted bar). Therefore, the number of components unique to either target or the distractors together with the size of the difference in the activation of shared components may both contribute to the ease or difficulty of search. When the target has no unique features and the distractors contain a large proportion of the shared features, the degree of similarity has a large effect. With an IC task, where targets are highly discriminable from non-targets, the target will pop-out regardless of whether within-dimension or between-dimension binding is required. Further, if the target is comprised of a unitary value then binding takes place at the pre-attentive stage of processing because these values are coarse coded so IC's should not occur.

While the research cited above would indicate that a purple target can pop-out when it contains a colour element not present in any of the other stimulus items, none have shown that it would pop-out when it does not or when it forms part of a non-target. Nor is the perception of turquoise explained when no such item was present. Therefore, experiments four, five and six examine in more detail the conditions under which participants may perceive purple or turquoise, or indeed any other binary colour within the illusory conjunction paradigm.

3.1.2 METHOD

3.1.2.1 DESIGN

Experiment four was designed to investigate both the conditions under which participants perceived purple and turquoise and the lack of an adjacency effect. Therefore, several changes were made. Three related to the way responses were made. First, the target identification presentation was changed from two rows of the three target colours to two rows of ten buttons (see section 3.1.2.5 below). Second, to reduce task demands, no location response was required. Finally, because of difficulties in participants remembering to click one of three buttons on the mouse to represent their confidence each time they made a response, a separate screen was added to record separate confidence ratings (confident, unsure or not confident) for the target shape and colour. Two further changes were also made. First, the positions of the stimuli in experiments one and two were completely randomised to encompass any location within the given parameters. In experiment four, to record the actual locations of the target and distractor within the string, stimuli positions were fixed at six possible locations (see figure 3.2). Secondly, a change was made to the number of trials for each condition. Rather than the two-thirds/one-third split in favour of *near* trials, this was

changed to a fifty/fifty split resulting in a total of 288 trials for each condition (576 experimental trials) as well as 12 practice trials. The dependent variable was the error rate for identification of the target.

3.1.2.2 PARTICIPANTS

There were eight participants. Four were either academic or administrative members of Sussex University and four were graduates from the wider community. There were three males and five females with ages ranging from 22 to 50 years. All participants reported having normal or corrected to normal visual acuity together with normal colour vision. No payment for participation was made as all expressed a strong interest in taking part.

3.1.2.3 APPARATUS/MATERIALS

Stimuli were displayed and responses recorded using a custom-written programme in Visual Basic 6. These were presented on a Dell Optiplex GX 280 computer with a 17 inch CRT colour monitor with screen resolution of 1024x768 (85 hertz refresh rate). A chinrest was used to ensure a viewing distance of 70cm so that 1cm on the display corresponded to 0.82^{o} of visual angle. Responses were made using a three-button Logitech serial mouse. All stimulus colours were measured using an Ocean Optics USB 2000 spectroradiometer.

3.1.2.4 STIMULI

Stimuli remained identical to those for experiments one and two as did the size of each letter (0.53^{o} vertical by 45^{o} horizontal) and interletter distance (0.45^{o} edge to edge). However, changes were made to their positioning (see figure 3.2). Rather than stimuli being located randomly within a virtual rectangle (9.32^{o} horizontal by 3.60^{o} vertical), six stimulus positions were fixed within the same size rectangle. The target was placed at either position two or four in each string location with the distractor always at position three.

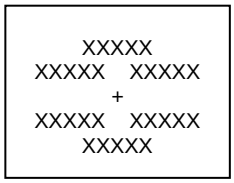


Figure 3.2: the six stimuli positions (not to scale)

3.1.2.5 PROCEDURE

As for experiments one to three, participants were tested individually and the apparatus arranged so that a viewing distance of approximately 70cm was achieved. An instruction sheet was provided stating the task requirements. The experiment was conducted over two days and commenced with a block of 12 practice trials. Each practice trial was identical to the experimental trials except that the stimulus display was visible for 200 msecs to allow participants to become accustomed to the task. Experimental exposure durations were controlled separately for each participant to reduce the rate of feature errors to approximately 10%. This was determined from the practice trials as follows: when error rates of less than 20% were recorded, the duration was reduced to 52 msec; when error rates fell between 20% and 40%, the duration was reduced to 104 msec; and when error rates greater than 40% were recorded, the duration was reduced to 147 msec.

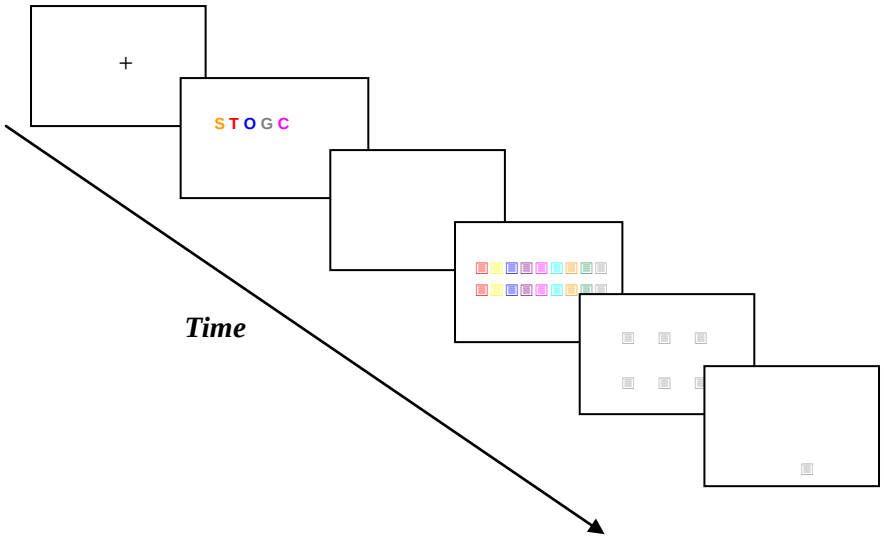


Figure 3.3: Representation of trial procedure (not to scale).

Each experimental trial proceeded as follows: first, a black fixation cross appeared in the centre of a white screen for 500ms followed by the stimulus display that appeared for 52 to 156 msec. This was followed by a 52 msec blank white screen. Next, 20 coloured target identification boxes appeared on the screen arranged in two rows of ten each. The top row represented the target letter T and the bottom row, the target letter X. The ten colours represented the three target colours (red, blue, yellow), the remaining non-target colours (orange, green, purple, pink and grey) together with lime

and turquoise which represented the intermediate binary colour for green and yellow and blue and green respectively. Participants were asked to click on the colour that most represented the target colour they had perceived. Next, a screen was visible with two rows of three boxes relating to how confident (confident, unsure and not confident) each was regarding first the letter, then the colour they had chosen. To give more control over the onset of each trial and to allow for rests when required, a further screen was presented containing a button to click when they ready to begin the next trial (see figure 3.3).

3.1.3 RESULTS

Two types of responses were recorded: whether the target letter was reported correctly or incorrectly and the perceived colour of the target. There were ten possible colour response categories and these are detailed in table 3.1.

Colour Response Category	Key	Near		Far	
		Letter Correct	Letter Incorrect	Letter Correct	Letter Incorrect
Target colour	NTDNN	63.11 (10.69)	1.13 (1.00)	74.44 (7.79)	1.09 (0.54)
Distractor colour	NTDNN	13.98 (5.55)	0.48 (0.55)	9.77 (6.49)	0.56 (0.81)
Non-target colour adjacent to target	NTDNN	4.25 (2.46)	0.09 (0.25)	2.00 (1.41)	0.09 (0.25)
Non-target colour adjacent to distractor	NTDNN	2.21 (1.63)	0.09 (0.25)	3.65 (1.87)	0.04 (0.12)
Incorrect colour	NTDNN	2.65 (1.75)	0.35 (0.45)	2.26 (1.76)	0.17 (0.26)
Non-adjacent non-target colour	NTDNN	4.82 (2.18)	0.09 (0.16)	2.39 (2.77)	0.39 (0.47)
Target and distractor fusion	NTDNN	4.99 (3.71)	0.09 (0.25)	0.56 (0.96)	0.04 (0.12)
Target and adjacent non-target fusion	NTDNN	1.56 (2.12)	0.00 (0.00)	1.87 (1.53)	0.09 (0.25)
Non-target and distractor fusion	NTDNN	0.09 (0.25)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Target and intervening colour fusion	NTNDN	n/a	n/a	0.09 (0.25)	0.00 (0.00)
Distractor and intervening colour fusion	NTNDN	n/a	n/a	0.39 (0.86)	0.00 (0.00)
Intervening colour between target and distractor	NTNDN	n/a	n/a	0.26 (0.74)	0.00 (0.00)

Table 3.1. Mean percentage (and standard deviation) of recorded identification responses for both conditions (near and far).

Target letter incorrect responses occurred on only 5% of all trials in both conditions and were omitted from further analysis. Those trials for which both the target letter and target colour were correctly identified (*letter correct/colour correct*) represented on average 63% of *near* trials and 74% of *far* trials. Responses categorised as *letter correct/colour incorrect* in which a reported colour was not attributable to any other category occurred in 3% and 2% of trials respectively. Responses categorised as *letter correct/non-target colour* were also observed. These represented 5% of *near* trials but only 2% of *far* trials. Responses categorised as illusory conjunctions only related to colour responses in which the target shape had been bound with the distractor colour (*letter correct/distractor colour*). These occurred in 14% and 10% of trials respectively. Two further response categories were added as participants also incorrectly bound either the target letter with a non-target colour adjacent to the target (4% of *near* trials and 2% of *far* trials) or they incorrectly bound the target letter with a non-target colour that was adjacent to the distractor (2% of *near* trials and 4% of *far* trials). In the *far* condition, participants also appeared to make an illusory conjunction between the target shape and the intervening non-target colour but these only represented 0.26% of trials.

While binary non-target colours were recorded as being perceived on some trials, of particular interest in this experiment was whether an intermediate binary colour would be reported that was not present in the display. As all four possible intermediate binaries (purple, turquoise, lime or orange) could have resulted from a fusion between two primary colours and these were included as response options. The type of response made resulted in three further categories. The first was an intermediate combination (binary) of the target and distractor colour and could result in either orange or purple being perceived. These represented 5% of *near* trials and 0.5% of *far* trials. The remaining two categories represented an intermediate binary of either the target colour with the adjacent non-target unitary colour green (2% of *near* trials and 2% of *far* trials) or with the distractor colour and adjacent non-target green and could result in either lime or turquoise being perceived. These occurred on 0.9% of *near* trials but none of the *far* trials. This would not only indicate that a binary non-target colour could pop-out in displays containing two unitary colours but that an illusory binary colour could be formed.

The significant main effect of interletter distance between *near* and *far* conditions showed that distance affected whether participants were able to correctly

identify the target, make illusory bindings or make feature errors ($F(1,7) = 20.24$, $p<0.01$). This was also reflected in the interaction between distance and identification for the number of responses made for each of the nine main response categories ($F(1,7) = 12.63$, $p<0.01$). However, no adjacency effect between the *near* and *far* conditions was again found for the *letter correct/distractor colour* response category: $t(7) = 2.18$, $p>0.05$.

To determine whether this finding was a result of a violation of Bouma's bound, the positioning of the target in relation to fixation was analysed. On one third of the total *near* trials (96 out of 288), the target was placed 1.27^{o} of visual angle either above or below the fixation cross. On another third, it was 1.76^{o} above or below the fixation cross. For the remaining third, it occurred 2.90^{o} of visual angle above or below the fixation cross. For the *far* condition, the target was similarly positioned at 1.43^{o} of visual angle above or below the fixation cross, 1.76^{o} above or below the fixation cross and 2.74^{o} above or below the fixation cross. Table 3.2 shows the mean percentage of the different illusory conjunction responses recorded at each position:

Near		**Far**	
Distance	**Mean %**	**Distance**	**Mean %**
1.27^{o}	12.89 (8.74)	1.43^{o}	16.56 (9.75)
1.76^{o}	55.39 (17.61)	1.76^{o}	21.72 (16.36)
2.90^{o}	31.73 (10.07)	2.74^{o}	61.72 (24.30)

Table 3.2: Mean percentage of letter correct/distracter colour trials by distance (visual angle) between the target and fixation.

Bouma's bound is contravened if the distance between the stimulus objects is equal to or less than half the distance between the target and a central fixation point. However, while interletter distance between the target and distractor was 1.80^{o} of visual angle (centre to centre) for the *far* condition, an intervening letter was placed between the target and distractor. In every stimulus location, the distance between the target and distractor violated Bouma's bound. Therefore, the lack of an adjacency effect can be attributed to this violation. These findings would also account for those response categories where an illusory binding of the target shape with a non-target item was recorded.

However, this finding and those for the two previous experiments may also be due to the way the data were analysed. In each case, the number of illusory conjunctions in which the distractor colour was perceived was compared for the *near*

and *far* conditions. However, this does not consider illusory conjunction responses in which the colour from the opposite side of the target to the distractor was perceived. Nor does it consider those illusory conjunction responses made with non-target items not adjacent to the target. It may therefore be more appropriate to compare the number of illusory conjunctions involving the adjacent colour from each side of the target with those from all other positions. For the *near* condition a pairwise comparison showed that there were significantly more illusory conjunctions made from an item adjacent to the target than from items located further away ($t(7) = 5.61$, $p<0.01$). However for the *far* condition the reverse was found ($t(7) = -3.68$ $p<0.01$). This latter result indicated that the distractor colour (comprised of a second target colour) was far more likely to be perceived than a binary non-target colour.

Confidence ratings for *target letter correct* responses were analysed to determine what proportion of illusory conjunction responses could be counted as guesses. Three possible confidence ratings were offered: *confident, unsure* and *not confident*. While redesigning the mode of response resulted in all participants providing ratings, very few responses were categorised as unsure. These were therefore amalgamated with *not confident* responses. Confidence ratings for letter correct responses are detailed in table 3.3.

Colour Response	**Near**		**Far**	
	Confident	**Not Confident**	**Confident**	**Not Confident**
Target colour	98.39 (2.07)	2.88 (5.41)	99.13 (0.99)	0.87 (0.99)
Distractor colour	97.63 (3.46)	2.38 (3.46)	94.50 (6.97)	5.50 (6.97)
Non-target colour adjacent to target	97.13 (4.19)	2.88 (4.19)	86.38 (35.04)	13.63 (35.04)
Non-target colour adjacent to distractor	95.83 (37.40)	3.57 (9.45)	95.29 (12.47)	4.71 (12.47)
Incorrect colour	17.63 (20.49)	82.38 (20.49)	2.25 (6.36)	97.43 (6.80)
Non-adjacent non-target colour	97.25 (6.32)	2.75 (6.32)	94.14 (12.33)	5.86 (12.33)
Colour fusions	98.33 (2.85)	1.67 (2.85)	96.53 96.050	3.47 (6.05)
Intervening colour between target and distractor	n/a	n/a	100 (0.00)	0 (0.00)

Table 3.3: Mean percentage (and standard deviation) confidence ratings for each of the 7 near and 8 far target letter correct response categories.

There were four sources identified for the type of illusory colour perceived for the *near* condition (*distractor colour, adjacent target, adjacent distractor* and *non-*

target colour). When amalgamated, these showed that on average, 97% were given a confident rating. Similarly, 98% of *both correct* trials were also recorded as confident but only 18% of *letter correct/colour incorrect* trials were rated as such. For the *far* condition, an additional category was obtained when participants chose the intervening colour between the target and distractor. When all five categories were amalgamated, these showed that, on average, 94% were rated as confident. While 99% of *both correct* responses were rated as confident, only 2% of *letter correct/colour incorrect* were. The high confidence rating given for the amalgamated illusory conjunction responses suggest that they were perceived as genuine perceptual phenomena. This was confirmed by pairwise comparisons with Bonferroni correction between the confidence ratings for illusory conjunction responses and for incorrect colour responses, in both the *near* ($F(1,7) = 70.28$, $p<0.01$) and *far* conditions ($F(1,7) = 200.99$, $p<0.01$): in both cases, confidence ratings were significantly higher for the illusory conjunction responses.

3.1.4 DISCUSSION

Results for experiment four indicate that target identification accuracy, in which both the target colour and shape were correctly identified, represented approximately 63% of *near* and 74% of *far* trials. When the different types of illusory conjunction responses were amalgamated, they amounted to 25% of *near* and 18% of *far* trials. As for experiment two, placing the stimuli well into parafoveal vision (4.90^o of visual angle) produced a higher number of illusory conjunction responses. In direct contrast to experiment two, there were considerably fewer responses recorded for a colour chosen that was not present in the trial (3% of *near* trials and 2% of *far* trials). It would seem likely that this was due to the increase in the number of colour choices made available for response.

To determine what proportion of illusory conjunction responses could be attributed to guessing, confidence ratings for both the *near* and *far* conditions were examined. These indicated that 98% and 99% of *both correct* responses and 97% and 94% of amalgamated illusory conjunction responses for both the *near* and *far* conditions were rated as confident but only 18% of *near* and 3% of *far letter correct/colour incorrect* responses were. This would suggest that both correct target and illusory conjunctions were perceived with a similar amount of confidence, indicating once again that illusory conjunctions may be considered to be genuine perceptual phenomena.

That no adjacency effect was initially found appeared to result from the way the data was analysed. By comparing illusory conjunction responses for the *near* and *far* conditions, only distractor colours were compared. Nevertheless, this indicated that a unitary colour was more likely to be perceived than a binary colour wherever it was placed in relation to the target. When responses for colours, whether unitary or binary, that were adjacent to both sides of the target were compared with non-adjacent colour responses for each condition, it became clear that proximity did have a role to play in the perception of illusory conjunctions. However, where a second unitary colour was included in the display, it was more likely to result in an illusory conjunction being formed, whatever its position, than to result in an illusory conjunction being formed with an adjacent binary colour. This lends some support to Treisman & Gormican's (1988) proposal that before attention is focused feature space is comprised of a set of unitary items such as red, blue, green and yellow. However, because binary colours were also perceived, it would suggest that feature space is more of a continuum with more featural information becoming available as the distribution of attention narrows. This finding should therefore be considered when the illusory conjunction paradigm is used.

The violation of Bouma's bound may account for the additional three types of illusory conjunction perceived (*letter correct/adjacent target colour*, *letter correct/adjacent distractor colour* and *letter correct/non-target colour*) in which a non-target colour was incorrectly bound with the target letter. Although the percentage of trials that resulted in these types of responses was very small (see table 7), when amalgamated, they accounted for 11% of *near* trials and 1% of *far* trials. The confidence ratings given to these types of response were also extremely high at 97% for both the *near* and *far* conditions as were the confidence ratings for *letter correct/distractor colour* responses. This suggests that participants had not guessed but rather perceived non-target colour and target shape conjunctions as genuine perceptual phenomena. Further, it would appear that all non-target elements in the display were included in the violation of Bouma's bound and crowded round the target (see also Freeman & Pelli, 2007; Huckauf, 2007). This finding is also consistent with Treisman's (1993) notion that features are free-floating when focused attention is prevented, provided that the contributing features form part of items that crowd round the target. As proposed in experiment two, it would appear from these results that *letter correct/colour incorrect* responses do not give a true reflection of the *colour incorrect*

response category but rather contained a number of illusory bindings comprised of a non-target colour. This may account for why many of the participants complained that the colour they perceived (purple) was not available as a response option.

All non-target colour responses were analysed to determine which of the non-target colours were perceived. A non-target colour was incorrectly bound with the target shape on 5% of all trials in the *near* condition and 3% of all trials in the *far* condition. For the *near* condition the non-target colour was green on 14% of trials, grey on 11% of trials, orange on 17% of trials, pink on 38% of trials and purple for 7% of trials. For the *far* condition, the non-target colour was green on 27% of trials, grey on 16% of trials, orange on 37% of trials and purple on 7% of trials. Although there were few occasions when a non-target was erroneously bound with the target letter, all non-target colours used in the experiment were represented in differing proportions. This is somewhat surprising given Treisman's (1991) suggestion that within-dimension features can be divided between primary (unitary) features and secondary (binary) features with only unitary features being identified in parallel. Thus, while the perception of a green non-target item can be accounted for, it is difficult to see how a binary non-target colour was perceived.

A further group of responses must also be accounted for. These represent response colours that were not used in the experiment but were a binary of both the target and distractor colour used. Although these responses represented only a very small number of the *target letter correct* trials (7% of *near* and 3% of *far* trials), they did occur with some consistency. While it would have been simple to dismiss these as simple feature errors had only purple and orange been reported, it was not easy to dismiss the reported perception of turquoise and lime. On those trials where blue and red were the target and distractor colours, purple was reported in 65% of *near* trials and 33% of *far* trials. Similarly, on trials where orange was not present as a non-target colour, it was reported in 23% of *near* trials and 54% of *far* trials when red and yellow were the target/distractor colours. Turquoise was perceived on 27% of *near* trials and 28% of *far* trials where a blue target/distractor colour was adjacent to a green non-target and lime was reported on 35% of *near* trials and 22% of *far* trials when yellow was adjacent to green.

This experiment attempted to determine not only the conditions under which the perception of both purple and turquoise take place but why no adjacency effect was observed for experiments two and three. The lack of an adjacency effect and the

perception of the non-target colour purple can both be attributed to the effects of crowding. When Bouma's bound is violated, all non-target items as well as the target fall within the attentional window so that an illusory conjunction can be formed from the target letter any item's colour. However, the perception of a binary comprised of both the target and distractor colour has not yet been adequately explained. Experiment five explores this in more detail.

3.2 EXPERIMENT 5

3.2.1 INTRODUCTION

While experiment four provided very few instances in which a binary colour was perceived which was comprised of the target and adjacent colour, confidence ratings indicated that these responses were probably not due to guessing. Therefore some explanation must be found for them. Although the number of colours represented on the colour response display was increased to reflect all stimulus colours, this still restricted participants to making discrete responses. The use of discrete measures is standard throughout attentional research, Prinzmetal *et al* (1998) presented colour stimuli on a colour wheel from which responses were also made (see figure 3.6). This enabled participants to respond by selecting a location on the colour wheel that most closely resembled the colour they had perceived. For example, rather than being able to respond only to the colours used in the display such as blue, if the colour perceived had been a reddish blue, participants were able to select the shade they had perceived.

However, this method also restricts participants to making a selection based on colour alone. In experiment five, discrete colour responses were replaced by a three-dimensional colour palette so that participants could select a response along the continua of hue, saturation and luminance. A further advantage to using a three-dimensional colour palette was in the type of data collected. In all previous experiments, participants' colour responses were either correct or incorrect. In this experiment, it was possible to measure both the magnitude and directions of the error. In this way it was hoped to determine not only the exact source of the colour responses but the conditions under which these could be obtained. Therefore, experiment five investigates in greater detail the conditions under which participants' colour perceptions vary using a unitary coloured target and distractor with binary non-targets. This should produce distinctive and clearly identifiable adjacent fusions should they occur.

3.2.2 METHOD

3.2.2.1 DESIGN

The changes made were designed to provide more detailed information about responses in which both the target and distractor colours were apparently perceived as a binary of the two. Firstly, the *far* condition of previous experiments was removed. This resulted in a total of 300 trials where the target was always adjacent to the distractor: 12 trials were practice trials followed by 288 experimental trials. To provide the same number of trials as in previous experiments, the number of participants was increased from eight to sixteen. Secondly, stimuli colours were changed so that no binary colour comprised of both the target and distractor colours was present in any of the colour strings. For example, on trials where blue and green were target and distractor colours turquoise was never used as a non-target colour. Finally, colour could now be reported by participants on a continuum. A three dimensional colour palette replaced the coloured buttons used for the colour responses to enable the hue, saturation and brightness of the perceived colour to be chosen and separately recorded (see figure 3.4). To ensure that colour responses were a true reflection of each participants' own perception of the colours used, a pre-test was conducted to measure each individuals perception of first, the hue, saturation and luminosity of the colours used in the experiment and second, the boundary between each unitary and binary colour.

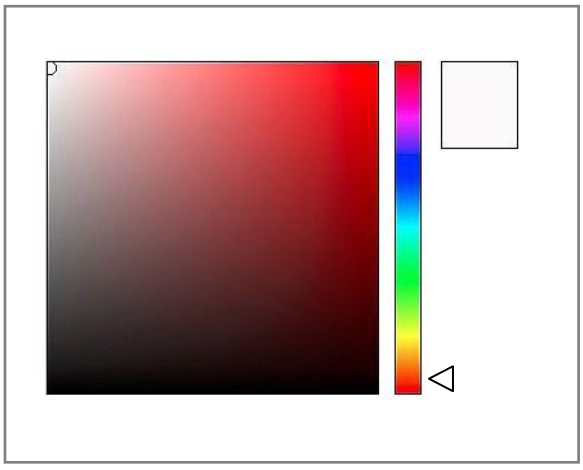


Figure 3.4: Representation of colour palette as shown on response screen. The circle in the top left-hand corner of the large box is moved to the right to increase saturation and down to decrease brightness. The arrow next to the rainbow bar is used to select hue. The resulting colour appears in the box on the right.

3.2.2.2 PARTICIPANTS

Participants comprised the eight from experiment four plus a further eight. Twelve were either academic, postgraduate or administrative members of Sussex University and four were graduates working outside university. There were seven males and nine females with ages ranging from 22 to 50 years. All participants had normal or corrected to normal visual acuity and normal colour vision. Participants who had not already done so completed the pre-test so that these data could be matched against their colour responses. No payment for participation was made but all expressed a keen interest in taking part.

3.2.2.3 APPARATUS/MATERIALS

Stimuli were displayed and responses recorded using a custom-written programme in Visual Basic 6 and run on a Viglen Genie 2 Plus and 17 inch CRT colour monitor with a screen resolution of 1024x768 (60 hertz refresh rate). A chinrest was used to stabilise the viewing distance at 70cm so that 1cm on the display corresponded to 0 82^{o} of visual angle. Responses were made using a standard Dell USB mouse.

3.2.2.4 STIMULI

Colour	**CIE *x* co-ordinate**	**CIE *y* co-ordinate**	**Luminance (cd/m^2)**
Red	0.61	0.35	4.27
Blue	0.16	0.1	2.43
Green	0.37	0.56	14.76
Orange	0.54	0.42	7.36
Magenta	0.3	0.17	6.09
Purple	0.32	0.19	1.54
Lime	0.45	0.49	10
Mauve	0.26	0.21	5.13
Turquoise	0.27	0.33	8.98
Aquamarine	0.27	0.34	3.71
Brown	0.51	0.44	3.11

Table 3.4: CIE colour co-ordinates for each stimulus colour.

While, no changes were made to the size, interletter distance between items or to their positions in the visual field, stimuli colours were changed. The target colours red and blue remained the same as for the previous experiment and green once again replaced yellow. Non-target colours were also changed to reflect elements of the unitary colours resulting in six colour strings: magenta, green, red, aquamarine and purple; turquoise, red, green, mauve and brown; turquoise, red, blue, orange and lime;

lime, blue, red, aquamarine and orange; magenta, green, blue, brown and mauve; lime, blue, green, mauve and orange. The CIE co-ordinates for each stimulus colour are shown in table 3.4 together with a representation of their respective colours and how discriminable they were.

3.2.2.5 PROCEDURE

As for previous experiments, participants were tested individually and the apparatus arranged so that a viewing distance of approximately 70cm was achieved. An instruction sheet was provided stating the task requirements.

A pre-test was conducted to record the individual elements of colour perception for each participant. It was comprised of two elements. First, a fixation cross was visible for 500 msec followed by each colour used in the experiment, also presented for 500 msec. Then the colour palette was presented and participants were required to match as closely as possible, the colour that they had perceived. Second, the colour palette was presented and participants were asked to record the point at which each colour changed. For example, they had to indicate the point at which red became orange, or blue became turquoise.

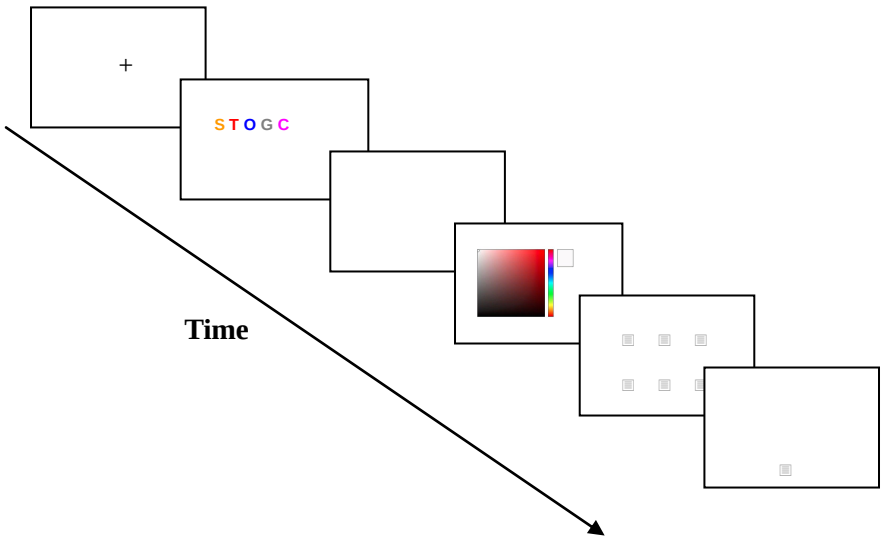


Figure 3.5: Representation of trial procedure (not to scale).

The twelve practice trials on day one were again used to determine the stimulus duration for each participant. Each experimental trial proceeded as follows (see figure 3.5): first, a fixation cross was visible in the centre of the screen for 500ms. This was followed by the stimulus display that appeared for 52 to 156 msec. This was followed by a 52 msec blank white screen. Next, the colour palette became visible together with

a box in which participants were to record what target letter they had seen. To record the colour they had perceived, participants were asked to move first the colour bar to select the hue, then to move a small white circle around the palette to record both saturation and luminance. Next, a screen was visible with two rows of three boxes to record how confident (confident, unsure and not confident), each participant was regarding first the letter, then the colour they had chosen. To give more control over the onset of each trial and to allow for rests when required, a further screen was presented containing a button to click when they were ready to begin a new trial. Participants were debriefed and thanked for their co-operation and a copy of the experimental rationale together with the results was offered once all the data had been collected and analysed.

3.2.3 RESULTS

Two types of responses were recorded: whether the target letter was correct or incorrect and the perceived colour of the target. There were seven possible colour response types and these are detailed in table 3.5. As *letter incorrect* responses in all categories only represented a total of 3% of all trials, these are not discussed further.

Colour Response	Key	Target Letter Correct	Target Letter Incorrect
Target colour	NTDNN	53.67 (8.04)	0.74 (0.59)
Distractor colour	NTDNN	21.20 (4.39)	0.59 (0.58)
Non-target colour adjacent to target	NTDNN	10.42 (4.34)	1.13 (1.43)
Non-target colour adjacent to distractor	NTDNN	2.28 (2.13)	0.20 (0.36)
Incorrect colour	NTDNN	3.26 (2.26)	0.20 (0.28)
Non-adjacent non-target colour	NTDNN	4.43 (2.78)	0.17 (0.34)
Target and distractor fusion	NTDNN	1.74 (1.09)	0.09 (0.23)

Table 3.5: Mean percentage (and standard deviation) of all recorded responses.

On 54% of trials, both the target letter and target colour were correctly identified (*letter correct/colour correct*). *Letter correct/colour incorrect* responses occurred on 4% of trials. Responses categorised as *letter correct/non-target colour* represented 3% of trials. Responses categorised as illusory conjunctions (*letter correct/ distractor colour*) occurred in 21% of trials. Response categories where participants incorrectly bound the target letter with an adjacent non-target colour rather than the distractor colour represented 10% of trials. On 2% of trials, they incorrectly bound the target letter with a non-target colour that was adjacent to the distractor. This clearly indicates the presence of an adjacency effect and this was confirmed by a pairwise comparison

between illusory conjunctions that were adjacent to the target and illusory conjunctions from a non adjacent position ($t(15) = 18.71$, $p<0.01$).

On 2% of trials, participants appeared to bind two stimulus colours with the shape of the target (*letter correct/colour fusion)*. The *colour fusion* response category was further analysed to determine which stimulus colours made up the perceived colour. Both magenta and turquoise accounted for all but three responses and both represented an intermediate binary of the target and distractor colour.

Confidence ratings for *target letter correct* responses were analysed to determine what proportion of illusory conjunction responses could be counted as guesses. Three possible confidence ratings were offered: *confident, unsure* and *not confident*. Due to low number of these types of responses, *not confident* and *unsure* ratings were amalgamated and are detailed in table 3.6.

Colour Response	Confident	Unsure/Not Confident
Colour correct	83.25 (19.43)	16.81 (19.38)
Distractor colour	70.69 (30.83)	29.25 30.89)
Colour adjacent target	69.63 34.35)	30.38 (34.35)
Colour adjacent distractor	53.63 (40.79)	33.88 (37.42)
Non-target colour	57.94 (38.42)	36.44 (37.30)
Incorrect colour	63.69 (36.33)	37.31 (37.29)
Colour fusion	63.63 (38.37)	38.80 (38.43)

Table 3.6: Mean percentage (and standard deviation) confidence ratings for target letter correct response categories.

There were four sources identified for the type of illusory colour perceived (*distractor colour, adjacent target, adjacent distractor* and *non-target colour*). When amalgamated, these showed that on average, 63% were given a confident rating. Similarly, 83% of *both correct* trials were also recorded as confident with 64% of *letter correct/colour incorrect* trials being rated as such. However, it should be noted that there is an extremely large variance between participants' ratings although this can be accounted for by differences between those participants that have completed a number of these experiments and those that have never taken part before. Under the circumstances, it is difficult to attribute the perceived illusory conjunctions as anything other than guesses. This was reflected in a pairwise comparison between amalgamated illusory conjunction responses reported as confident and confident responses recorded as a colour not attributable to any other category ($t(15) = 0.99$, $p>0.05$).

3.2.4 DISCUSSION

Results for experiment five indicate that target identification accuracy, in which both the target colour and shape were correctly identified, represented approximately 54% of trials. Illusory conjunction responses amounted to 34% of trials in total and confidence ratings indicated that while none could be deemed true feature binding errors, this was wholly due to ratings made by participants who had not taken part in previous experiments. This was confirmed by a pairwise comparison $t(7) = 4.79$, $p<0.01$. Those new to the experiment were extremely cautious in their confidence ratings regardless of whether they correctly identified the target, made an illusory conjunction or perceived a colour not present. Some participants also found using the three-dimensional colour palette took so long that they found it difficult to maintain in memory the exact colour they were trying to match. However, this did improve dramatically when familiarity in using the colour palette speeded up response times. Under the conditions described by Treisman & Schmidt (1982) it is difficult to attribute illusory conjunction responses to anything but guesses and therefore no conclusions can be reliably drawn.

Response categories that imply a fusion of the colours from two adjacent items and represent colours that were not used in the experiment indicated that very few *target letter correct* trials (2%) were perceived as such, which is considerably lower than that found for the previous experiment (7%). Of these, the majority appeared to be a fusion between the target and distractor colours. This resulted in a reasonably even proportion of the two possible resulting colours being perceived (turquoise 56% and magenta 44%). It would have been easy to dismiss these responses as there were so few of them. However, when taken together with those found for experiment four, they appear to show that some form of within-dimension binding is taking place, as well as the between-dimension binding of the resulting colour fusion with shape.

Of particular interest in this experiment was whether the inclusion of a three-dimensional colour palette would reveal more detailed information about the colours that had been perceived. The results clearly indicated that participants made a wider variety of colour responses than had been available to them before. The reduction in the number of *colour fusion* responses from that found for experiment four is surprising but presumably due to the changes made in the colour strings. However, in what way has yet to be determined. A second unexpected finding was participants' reports of the non-target colour magenta. Not only was this colour not unique, in that it was

represented elsewhere in the display but it was also of a lower luminosity than adjacent colours. This is contrary to the body of research showing that only salient colours pop-out in a display (e.g. Cave, 1999; Cave & Wolfe, 1990; Desimone & Duncan, 1995; Koch & Ullman, 1985; Treisman & Sato, 1990; Wolfe *et al*, 1989). Therefore experiment six examines colour perception under conditions of shape and/or colour similarity**.**

3.3 EXPERIMENT 6

3.3.1 INTRODUCTION

In the previous experiment, participants not only perceived what appeared to be colour fusions but also reported seeing a binary coloured item (magenta) whose contributing elements were not only present elsewhere in the display but were of lower luminosity than an adjacent unitary colour. Duncan & Humphreys (1989) suggested that when non-targets share common features, search should be marginally more difficult and therefore slower than if they had been heterogeneous. Further, when the non-targets do not share a feature contained in the target, search will be faster than if each non-target shares a feature common to the target. Treisman (1991) also suggests that unitary features are coarsely coded at very early stages of processing but that binary features which are comprised of a combination of two or more unique features are far more difficult to identify and therefore take longer to process. Indeed, many models of visual attention propose that a salient item which differs from all others in the display in at least one feature will attract attention (e.g. Cave, 1999; Cave & Wolfe, 1990; Desimone & Duncan, 1995; Koch & Ullman, 1985; Treisman & Sato, 1990; Wolfe *et al*, 1989).

However, other researchers have been unable to show that a unique colour will attract attention in a bottom-up manner, suggesting that a unique colour will only pop-out if it is associated with the target (e.g. Folk & Annett, 1994; Gibson & Jiang, 1998; Jonides & Yantis, 1988; Northdurft, 1993b; Theeuwes, 1990; Todd & Kramer, 1994). Turatto & Galfano (2001) investigated attentional capture using a standard search task with a target that would not pop-out and in which the colour was irrelevant. For example, in their first experiment, they embedded the target, a T rotated at 45^{o} in a coloured disk among embedded L's, some of which were upright and some also rotated at 45^{o}. Only one of the upright distractors was of a different colour (e.g. green) to the rest of the display (e.g. red), including that of the target. They found that the salient

(unique) colour produced an involuntary shift of attention even when the item had a low probability that it contained the target. From their results, they proposed that colour is processed at a very early preattentive level, consistent not only with FIT but with other models of visual attention (Cave, 1999; Cave & Wolfe, 1990; Duncan & Humphreys, 1989; Wolfe *et al*, 1989).

Using these criteria, it is extremely difficult to determine why, when the target shape is correctly identified, magenta popped-out in displays where the binary non-targets and distractor contained a colour present in magenta (blue or red) and the target was the only unique colour (green) or where the binary non-targets and target contained a colour present in magenta (blue or red) and the distractor was the only unique colour (green). In both cases, the unique green, whether it was the target or distractor, would have been expected to pop-out. Further, the trials in which magenta popped-out were not restricted to red and green targets and distractors indicating opponent colour inhibition (Jameson & Hurvich, 1955) but also occurred when these were green and blue as well. Using homogenous displays of shape and/or colour, this finding was investigated further.

3.3.2 METHOD

3.3.2.1 DESIGN

Experiment six was identical to experiment four in respect of apparatus/materials and participants. The procedure was identical to that used for experiment five. There was a total of 576 experimental trials, 288 experimental trials plus 12 practice trials for each condition. The experiment was conducted over two days. Half of the participants completed condition one on day one and condition two on day two, with the remaining participants completing both conditions in reverse order. The stimuli were changed to displays of similar shape (condition 1) and binary colour (condition 2). The target shape remained the same as for previous experiments (T or X) however, there were no designated target colours. Participants were required to identify both the target shape and colour. Using displays entirely made up of either homogenous shapes with unique target/distractor colours and binary colours with a unique target shape, it was hoped to explore further the conditions under which the non-unique target colours are perceived.

3.3.2.2. STIMULI

For condition one, various letter combinations were tested on three participants. However, when the target was embedded within strings that were highly similar, such as a T embedded among H L F E they were unable to identify it. Therefore, while the target letters remained the same (T or X), the letter strings were changed so that although no curved lines were contained within any one letter, the T was embedded within letters comprised of diagonal lines and the X within letters comprised of horizontal and vertical lines: N Z T V Y; Y N T Z V; V Y T N Z; Z V T Y N; L F X E H; H L X F E; E H X L F and F E X H L. The target was always presented in position three. While this positioning may have facilitated identification of the letter, the stimuli were presented randomly in any one of six different positions in the visual field which should have mitigated any benefits gained. For condition two, letter strings were identical to those used in all previous experiments.

Colours for condition one remained identical to those used for experiment four. For condition two, all items in the display were comprised of the binary colours used for experiment five with the addition of pink. The CIE co-ordinate for pink was: x = 0.36, y = 0.29, luminance = 10.08 cd/m^2.

3.3.3. RESULTS

Again, two types of responses were recorded: whether the target letter was correct or incorrect and the perceived colour of the target. The mean percentage for the six resultant colour response categories and two letter response categories are detailed in table 3.7.

	Key	Similar Shape		Binary Colour	
Colour Response		**Target Letter Correct**	**Target Letter Incorrect**	**Target Letter Correct**	**Target Letter Incorrect**
Target	NNTNN	45.01 (6.40)	1.30 (0.87)	34.03 (10.49)	0.56 (0.72)
Distractor	NNTNN	32.51 (8.86)	0.52 (1.08)	n/a	n/a
Adjacent target	NNTNN	10.07 (4.86)	0.61 (0.76)	21.83 (7.36)	0.52 (1.08)
Non-adjacent target	NNTNN	3.56 (4.13)	0.48 (0.87)	11.59 (5.23)	0.61 (0.76)
Colour shifts	NTNNN	4.56 (2.24)	0.39 (0.47)	22.22 (13.74)	1.26 (0.32)
Colour shift/fusion	NTNNN	1.09 (0.95)	0 (0)	7.00 (4.24)	0.69 (0.48)

Table 3.7: Mean percentage (and standard deviation) of recorded responses for each category for both the similar shape and binary colour conditions.

For the *similar shape* condition, only 3% of all trials produced responses recorded as *letter incorrect*. This is comparable to the rate found for previous experiments where T/D similarity was extremely high. Trials where both the target

letter and target colour were correctly identified (*both correct*) represented 45% of trials. As one of the three target colours was used as a distractor colour in this condition, three types of illusory conjunction responses were identified: those comprised of the distractor colour (*letter correct/distractor colour*); those comprised of the colour from the item immediately to the left of target (*letter correct/adjacent colour*); and those comprised of the colour from either of the two non-adjacent items (*letter correct/non-adjacent colour*). These represented 33%, 10% and 4% of trials respectively. As can be seen in table 3.7, a further response category has been added (*colour shifts*) in which reports showed a high degree of consistency in the type of colour (hue, saturation and luminance) response observed that would normally be recorded as incorrect or as a potential colour fusion. Similar findings have been shown by both Prinzmetal *et al* (1998) and Rosch (1975). Therefore this finding warranted the re-evaluation of both the *colour fusion* and *incorrect colour* categories. All *incorrect colour* responses could be attributed to a similar colour shift. However, for the *colour fusion* category, although a distinct colour shift could be distinguished from potential fusions on some of these trials, due to the colours used for the stimulus display this was not always possible. Therefore, this category remains (*letter correct/colour shift/fusion*) and represented 1% of trials. The new *letter correct/colour shift* category represented 5% of the total trials.

For the *binary colour* condition, there was no designated target or distractor colour. This resulted in the proportions of responses for each category being somewhat different from that found for the similar shape condition. Responses recorded as *letter incorrect* again represented only 4% of all trials and are not discussed further. Trials where the target letter and colour were correctly identified (*both correct*) represented 34% of trials. Two types of illusory conjunction responses were identified: those that were comprised of a colour from an item adjacent to the target (*letter correct/adjacent colour* and those comprised of a colour from an item that was not adjacent to the target (*letter correct/non-adjacent colour*). These represented 22% and 12% of trials respectively. Responses recorded as a colour shift (*letter correct/colour shift*) represented 22% of trials. Trials for which it was not possible to be certain a colour shift had been perceived (*letter correct/colour shift/fusion)* represented 7% of the total trials. No *letter correct/colour incorrect* responses were recorded.

An adjacency effect was apparent for both the *binary colour* (and *similar shape* conditions. This was confirmed by pairwise comparisons between illusory conjunctions

comprised of a colour adjacent to the target and those illusory conjunction comprised of a colour from an item not adjacent to the target (*similar shape* condition $t(7) = 3.33$, $p<0.05$; and *binary colour* condition $t(7) = 3.24$, $p<0.05$).

Colour Response	Similar Shape		Binary Colour	
	Confident	Unsure/ Not Confident	Confident	Unsure/ Not Confident
Target	74.08 (20.33)	25.82 (20.29)	74.13 (32.22)	26.81 (31.53)
Distractor	72.58 (18.57)	27.42 (18.57)	n/a	n/a
Adjacent target	56.79 (36.56)	43.21 (36.56)	57.29 (39.45)	42.71 (37.37)
Non-adjacent target	45.52 (33.64)	71.46 (40.85)	50.54 (37.37)	49.46 (31.55)
Colour shifts	34.28 (36.22)	65.72 (41.29)	45.89 (33.79)	54.11 (33.79)
Colour shift/fusion	43.45 (42.07)	56.55 (42.07)	52.38 (39.66)	47.62 (39.66)

Table 3.8: Mean percentage (and standard deviation) confidence ratings for target letter correct response categories in both conditions.

Confidence ratings for *target letter correct* responses were analysed to determine what proportion of illusory conjunction responses could be attributed to guessing. Both *unsure* and *not confident* ratings were combined as before and these are detailed in table 3.8. What is most noticeable for this experiment is the reduction in confidence when a colour error is reported regardless of whether it was an illusory conjunction or a shift in colour space. For condition one (*similar shape*) the three types of illusory colour responses were amalgamated and showed that only 58% of these trials were given a confident rating, while 74% of *both correct* trials were recorded as such. While no incorrect colour responses were recorded, the reports categorised as *letter correct/colour shift/fusion* may in fact, be incorrect. These showed that 43% of these trials were given a confident rating and when matched against the amalgamated illusory conjunction responses they indicated that illusory conjunctions were unlikely to have been perceived as anything other than guesses. This was confirmed by a pairwise comparison between *letter correct/colour shift/fusion* and the amalgamated illusory conjunction responses ($t(7) = 2.33$, $p>0.05$).

For condition two (*binary colour*), as no distractor colour was used there were only two types of illusory conjunction responses (*letter correct/adjacent colour* and *letter correct/non-adjacent colour*). When amalgamated, again only 54% were confident whereas 74% of *both correct* trials were recorded as such. When illusory conjunction confidence reports were analysed, participants were equally likely to rate adjacent non-target colour responses as confident (52%) as they were non-target colours placed further away (51%). However, while no incorrect colour responses were

recorded, there were some uncertainty over those colour responses recorded as *letter correct/colour shift/fusion* for which participants rated 48% as confident. This again makes it likely that a proportion of the illusory conjunction responses could be attributed to guessing. This was confirmed by a pairwise comparison ($t(7) = 0.33$, $p>0.05$) showing that participants were no more likely to rate a reported illusory conjunction as confident than they were a possible colour shift/fusion.

3.3.4 DISCUSSION

Results for experiment six found, as expected, that for the *binary colour* condition, the target letter was correctly identified on 97% of trials. Similarly, for the *similar shape* condition, the target shape, which had been embedded within non-targets comprised of straight lines (e.g. T among N Z V Y), was also correctly identified in 97% of all trials. This is comparable to previous experiments in which a heterogeneous target shape was placed among similar but not identical distractor/non-target shapes.

Both the target colour and shape were correctly identified on 45% of trials for condition one (*similar shape*). For condition two (*binary colour*) *both correct* responses represented 34% of trials. This is a considerable reduction from previous experiments and while it is understandable for the *binary colour* condition, participants made very few shape errors (3%) for the *similar shape* condition and the colours used were identical to those for experiment five. However, this is consistent with Khurana's (1998) finding that rather than illusory conjunctions being formed when objects were perceptually grouped, it was always colour that was mislocalised not shape.

Amalgamated illusory conjunction responses amounted to 46% of trials for the *similar shape* condition and 33% for the *binary colour* condition. This is comparable to the number found for experiments three and four. However, compared to those experiments, participants were far less inclined to rate their responses as *confident* for both the *similar shape* and *binary colour* conditions in this experiment, regardless of whether they were correct, made an illusory conjunction, perceived a colour shift or responded with a colour that could have resulted from either a tritan-like colour shift or a colour fusion. It would appear that homogenous displays of either colour or shape resulted in participants being far less certain that they had perceived the target correctly.

While participants clearly found difficulty in perceiving the binary colour that comprised the target when it contained no unique element, 34% of *both correct* trials were correctly reported with a 52 msec exposure duration. This would suggest that binary values can also be coarsely coded at an early stage of processing. However,

while such results indicate the presence of detection mechanisms tuned to intermediate binary colours as proposed by D'Zmura (1991), only 17% of *both correct* trials contained a target comprised of a unique element. On the majority of these trials (83%), both adjacent non-target items were comprised of one element of the target colour. This is contrary to D'Zmura's (1991) suggestion that the mechanisms required for parallel search can distinguish binary colours provided that both target and distractor colours are linearly separated in colour space. It also contradicts Treisman's (1991) suggestion that it is only unique unitary values that are processed in this way. Further, target colours were often of lower luminance than either one or both adjacent non-target colours. However, although the position of the stimulus was randomly moved from trial to trial to one of six possible positions in the visual field, for this experiment, the target was always placed in position three of the string and it may well be location that is the source of the salience as suggested by Põder (2006).

For the *similar shape* condition, adjacent illusory conjunction responses were divided into those that were comprised of the target shape being bound with the distractor colour (33%) and those in which the non-target colour was positioned directly to the left of the target (10%). For the *binary colour* condition, adjacent illusory conjunctions amounted to a total of 22%. Illusory conjunctions comprised of a colour from an item that was not adjacent to the target amounted to 4% for the *similar shape* condition and 12% for the *binary colour* condition. This indicated that a non-adjacent binary colour could be bound with the target shape even when two unitary colours were present in the display (*similar shape* condition). These results lend further support to Treisman (1993), who maintained that features within a display are free-floating in relation to one-another before the focus of attention is applied provided, that is, no stimulus position in the display conformed to Bouma's bound.

While it was not possible to reassign any of the *letter correct/incorrect colour* responses and only some of the colour responses (*letter correct/colour shift/fusion*) in both conditions due to a potential colour shift resulting in the same colour report as a fusion between two colours used in the stimulus array. However, it did become apparent when analysing the data that for many of the *both incorrect* responses, as well as for a proportion of those responses for the *colour fusion* category, that certain colours were consistently being perceived across participants. This indicated that a colour shift had occurred rather than that two adjacent colours had been fused or that a colour had been guessed.

Evidence for colour shifting was found by Rosch (1975) who showed that the perception of a binary colour shifts towards a prototypical (unitary) colour when focused attention is prevented. More recently, Prinzmetal *et al* (1998) investigated whether colour shifts were reduced with varying amounts of attention. Instead of using colour naming as the response, they presented participants with a continuous colour wheel containing 254 colours (see figure 3.6).

Figure 3.6: Standard continuous colour wheel

Nine letters in a three by three matrix were placed inside the colour wheel. The target letter was a T or an F which was visible for 67 msec. A coloured dot was also presented for the same duration at one of two fixed peripheral locations (both encompassing 8.2^{o} of visual angle). Target colours were comprised of the four unitary and four binary colours with saturation and luminosity both kept constant with that of the corresponding colour on the colour wheel. In experiment one, presentation of the letters and coloured dot was either simultaneous or sequential. Participants were first required to match the target dot colour as closely as possible on the colour wheel using a mouse then to indicate on the keyboard whether the letter T or F was present. Prinzmetal *et al* (1998) found that when attention was diverted, in the simultaneous presentation condition, responses appeared to show a mean shift in the perception of colour. This indicated that diverting attention produced greater uncertainty as to the target's colour. However, of more interest was the direction of the colour shift. They found that while the majority of colour responses moved with varying degrees in a clockwise direction, for example red was perceived to be more yellowish (orange), three colours appeared to move in an anticlockwise direction. Thus, green appeared to take on a yellowish colour (lime), blue appeared as more greenish (turquoise), and purple appeared more blue. While these results may account for the perception of turquoise in the present experiments, they do not account for the perception of purple or orange,

since although red appears to shift towards orange, this is by an extremely small amount and it should be perceived as remaining firmly red. Purdy (1931a/b) however, found that red was perceived as shifting towards blue and perceived as purplish rather than orange.

The results from experiments three to five all indicate that very brief display times may result in a shift in the perception of unitary colours, for example blue appearing to shift towards green so that a bluish green (turquoise) is perceived (Prinzmetal *et al,* 1998) and red appearing to shift towards blue giving purple (Purdy, 1931a/b). The results of experiment six would indicate that it is a colour shift that is the cause of perceived fusions rather than the perception of a binary colour comprised from two adjacent items.

If this is the case, then this would affect the results from all of the response categories in the previous experiments and indeed, other research using multiple colours and not just those responses categorised as incorrect. For example, it is possible that that a distractor colour was recorded when, in fact, the target colour had been correctly perceived but with a colour shift. It may also have resulted in the colour response being recorded as incorrect thereby distorting any test used to determine whether guessing had taken place. It would also explain apparent colour fusions, in which the target and distractor colours appeared to bind to form a third colour. When the *colour fusion* responses were re-examined from experiments three and four, it was found that all could be equally explained as a colour shift except for turquoise responses. However, with the colours used, it is impossible to distinguish between a colour shift and a fusion. Therefore, in experiment seven, this phenomenon is explored further.

3.4 EXPERIMENT 7

3.4.1 INTRODUCTION

While colour shifts have been observed by other researchers (Prinzmetal *et al*, 1998; Rosch, 1975), the colour shifts observed in experiment six did not consistently move in the same direction. For example, while turquoise appeared to consistently move in the direction of blue as found by Prinzmetal *et al* (1998), green also appeared to shift to blue and not lime, while orange appeared to shift towards pink rather than yellow. To examine colour shifts and fusions in more detail, a new series of colour strings was devised.

3.4.2 METHOD

3.4.2.1 DESIGN

The total number of trials, apparatus and procedure all remained identical to that of experiment five. However changes were made to the number of stimulus items in the display and the colours. Stimulus strings were reduced from five to four items. To prevent the stimulus colours from being perceived as darker when a white background is used on a CRT monitor rather than when either a grey or black background is used (see Wickins & Andre, 1990), the display background and mask were changed from white to grey (CIE co-ordinates: x =0.34, y = 0.34; luminance = 4.60).

3.4.2.2 PARTICIPANTS

Participants comprised four academic, postgraduate or administrative members of Sussex University and four graduates working outside university. There were three males and five females with ages ranging from 22 to 52 years. All participants had normal or corrected to normal visual acuity and normal colour vision. Participants who had not taken part in previous experiments completed the pre-test which recorded their perception of the hue, saturation and luminosity of the colours and their boundaries which were used in the experiment. This enabled these data to be matched against their colour responses. Again, no payment for participation was made but all expressed a keen interest in taking part.

3.4.2.3 APPARATUS/MATERIALS

Stimuli were displayed and responses recorded using a custom-written programme in Visual Basic 6 and run on a Dell Dimension 8100 and 17 inch CRT colour monitor with a screen resolution of 1024x768 (60 hertz refresh rate). A chinrest was used to stabilise the viewing distance which was reduced to 60cm so that 1cm on the display corresponded to 0.95^{o} of visual angle. Responses were made using a standard Logitech USB two-button mouse.

3.4.2.4. STIMULI

All stimulus strings were reduced from five to four items to accommodate the limited colour combinations that could be used. However, when the stimulus strings were tested on three participants, they each found the experiment considerably harder to do than previous ones despite the reduction in the number of items. Therefore, the viewing distance was reduced to 60cm to increase the size of the stimulus array. This resulted in each letter subtending approximately 0.62^{o} vertical by 0.53^{o} horizontal (20 x

17 pixels) of visual angle at a viewing distance of approximately 60cm. Each letter was separated horizontally from its neighbour by approximately 0.53^{o} of visual angle (17 pixels) edge to edge. The letter strings were placed in either the upper or lower visual field. The regions were 4.76^{o} of visual angle to the left or right and extended 1.53^{o} vertically above or below the fixation point. Target letters remained as T or X and were randomly placed in either position two or three of the four item display. Non- target letters were comprised of: O S G; U G C; G C S and U C O. This resulted in 16 letter strings in all. Nine colour strings were devised: lime, blue, green and purple; lime, blue, yellow and purple; turquoise, green, yellow and purple; lime, blue, green and brown; brown green, red and lime; turquoise, blue, yellow and mauve; mauve, green, blue and orange; lime, red, green and brown; mauve, yellow, blue and lime. Saturation was at maximum for all colours excepting purple and brown. The CIE co-ordinates for each stimulus colour used in the experiment can be found in table 3.9.

Colour	**CIE *x* co-ordinate**	**CIE *y* co-ordinate**	**Luminance (cd/m^2)**
Yellow	0.43	0.46	20.15
Blue 1	0.26	0.21	7.96
Blue 2	0.16	0.10	2.43
Green	0.37	0.46	16.65
Red	0.51	0.32	6.71
Purple	0.32	0.23	7.63
Turquoise	0.31	0.37	17.06
Orange	0.47	0.39	11.12
Lime 1	0.41	0.46	14.51
Lime 2	0.45	0.50	10.00
Mauve	0.32	0.23	7.63
Brown	0.51	0.44	3.11

Table 3.9: CIE co-ordinates for each colour used

3.4.3 RESULTS

Responses are recorded as the mean percentage for each response category across participants and are detailed in table 3.10. Those responses recorded as *letter incorrect* represented 4% of trials. This is comparable with the proportion found for previous experiments and therefore no further analysis was undertaken. Trials where the letter was correctly identified provided the following proportions: responses where the target colour was correctly reported (*letter correct/colour correct*) represented 51% of trials, responses categorised as illusory conjunctions (*letter correct/distractor colour*)

occurred on 22% of trials; and those recorded as a colour adjacent to either the target or the distractor represented 17% (*letter correct/non T/D colour*) of trials. No colour fusion (*letter correct/colour fusion)* or *letter correct/colour incorrect* responses were recorded. It would appear that colour shifts accounted for both types of responses. These (*letter correct/colour shift)* responses occurred on 5% of trials.

	Target Letter Correct	**Target Letter Incorrect**
Colour Correct	51.19 (9.01)	2.21 (1.55)
Distractor Colour	22.29 (3.94)	1.04 (1.18)
Non T/D Colour	17.45 (3.64)	0.67 (0.39)
Colour Shifts	5.25 (5.63)	0.35 (0.36)
Incorrect Colour	None	None

Table 3.10: Mean percentage (and standard deviation) of recorded responses for each category.

Results for the illusory conjunction responses (*letter correct/distractor colour* and *letter correct/non T/D colour*) indicated that there was a strong adjacency effect. This was confirmed by pairwise comparisons between those items that were directly to the left or right of the target and those items that not directly adjacent to the target ($t(7) = 15.07$, $p<0.01$).

Confidence ratings for *target letter correct* responses were analysed to determine what proportion of guesses could be attributed to illusory conjunction responses and these are detailed in table 3.11. While 88% of *both correct* responses were recorded as 'confident', 82% of all illusory conjunction responses (*letter correct/distractor colour* and *letter correct/non T/D colour*) were also given a 'confident' rating. No *letter correct/colour incorrect* responses were recorded and this strongly indicates that illusory conjunction responses could not be attributed to guesses.

	Confident	**Unsure**	**Not Confident**
Colour Correct	88.11 (13.93)	7.56 (10.58)	3.35 (4.38)
Distractor Colour	82.62 (19.42)	13.82 (14.71)	3.56 (4.91)
Non T/D Colour	82.36 (21.27)	12.66 (16.75)	4.98 (4.69)
Colour Shift	64.69 (29.13)	26.44 (21.16)	8.88 (9.73)
Incorrect Colour	None	None	None

Table 3.11: Mean percentage (and standard deviation) confidence ratings for each target letter correct response category.

3.4.4. DISCUSSION

Results for experiment seven indicate that incorrect target letter identification was comparable to that found for previous experiments. The change from a white to a

grey background appeared to affect participants' performance while completing the task. All were observed to take considerably more breaks than for previous experiments and showed evidence of tiredness to a greater or lesser degree, with the time taken to complete the trials rising to approximately 1¼ hours as opposed to ¾ of an hour for previous experiments. Indeed, when the experiment was repeated by two participants using a white background to increase the contrast between the stimuli and background, both completed it within the same timeframe as for previous experiments. Nevertheless, these data equated reasonably well with previous levels of correctly identified targets.

Amalgamated illusory conjunction responses occurred on 40% of trials. This is comparable to the proportion found in experiment five. Confidence ratings suggested that true feature binding errors were being perceived. Of particular interest was that no *incorrect colour* responses were recorded at all. The redefinition of responses appears to have reduced the number of *incorrect colour* responses to zero. However, further investigation of those responses recorded as colour shifts is needed to determine whether this was a true reflection of participant's observations or not.

Choosing colour strings that could distinguish between a colour shift and a colour fusion of two adjacent colour features indicated that this type of colour fusion was unlikely to be taking place. However, the recorded colour shifts did not mirror those reported by Prinzmetal *et al* (1998) and not all stimulus colours appeared to shift. For example, colour shifts were only recorded for green, blue, turquoise and lime. While Prinzmetal *et al* (1998) found that blue shifted towards turquoise and vice-versa which also appeared to occur in this experiment, they suggested that green shifted towards lime whereas here it was perceived as either turquoise or blue. It was clear that rather than all stimulus colours being perceived as a colour shift on at least some trials, by far the vast majority occurred for blue, green or turquoise. It has been suggested that the colour shifts reported here are consistent with those observed for transient tritanopia in participants with normal colour vision (Troscianko, personal communication).

Transient tritanopia, a term first coined by Mollon and Polden in (1975), was first observed by Willmer (1944) who found that people with normal vision sometimes perceived a target colour presented in the central fovea in a similar way to those people who were blue-yellow colour blind (König, 1903). König (1903) observed, for example, that tritanopes confused greenish-yellow with grey or rose-purple; blue-green with blue; yellowish-green with bluish violet; and orange with reddish purple.

Transient tritanopia is a low-level retinal effect resulting from a problem with adaptation (Stiles, 1949). Mollon and Polden in (1975) suggested that a loss of short-wavelength sensitivity occurs when a long-wave adapting stimulus is suddenly removed. When normal trichromatic colour vision becomes dichromatic, the resulting tritan confusions occur when stimuli are small in size (Willmer, 1944); located parafoveally (Gordon & Abramov, 1977); when briefly presented (Weitzman & Kinsey, 1967 – although see Mollon, Astell & Cavonius, 1992); or when illumination is reduced (Middleton & Mayo, 1952). However, while a tritanope's inability to perceive short wavelengths results in blue being seen as aquamarine and yellow as pink or white, transient tritanopia behaves somewhat differently. Middleton & Holmes (1949) measured induced tritanopia in observers with normal vision and found that in chromaticity space, while red, orange and turquoise are not perceived to shift, yellow, lime and green are perceived with blue added. However, blue, violet and mauve are perceived with blue subtracted. Middleton & Mayo (1952) also found an increase in the number of blue to green responses to stimuli when the visual system moves from trichromatic to tritan-like.

The colour responses from the present experiment have indicated that it is unlikely that two unitary colours are binding to form a third, binary colour. Rather, there is a strong indication that not only do colour shifts take place but that these may be tritan-like in nature. When this type of response is considered, every reported colour could be accounted for and may indicate that issues of guessing in relation to illusory conjunctions might not, after all, be such a problem. Rather, responses recorded as guesses may, in fact, be legitimate and due to induced tritanopia. However, considerably more data are required before a definitive answer can be given.

3.5 INTERIM DISCUSSION

What has emerged from these experiments is that colour perception does not appear to be restricted to those colours presented. For instance, one of a string of coloured items in a display may be perceived as the actual colour of that item or may be perceived as the item's colour shifted along the chromaticity spectrum so that for example, green is perceived as blue or turqoise. It was suggested (Troscianko, personal communication) that the colour shifts noted above may be the result of stimulus colours being perceived in a tritan-like manner. Evidence for transient or induced tritanopia has been clearly demonstrated and can occur for a number of reasons. Most importantly for

this thesis, it can occur when stimuli are presented parafoveally or briefly (Godon & Abramov, 1977; Weitzman & Kinsey, 1967). That no incorrect colour responses were recorded in experiment seven once all colour shift reports had been accounted for in this way indicates that this may, indeed, be the case.

Experiment four also revealed that the adjacency effect was constrained not only by whether unitary or binary colours were adjacent to the target but on whether the colour red was an element contained within the colour string and where it was located.

In sum, like form, colour is clearly a global feature comprised of the three elements of hue, saturation and brightness, all three of which need to be considered. The colours we perceive in the visual field can appear to shift. However, in what way will these findings affect the perceived location of objects? This is one of the questions that is asked in experiment nine. However, all of the colour strings used in this experiment meant that it was difficult to clearly distinguish which exact colour had shifted and this, together with the implications for the perceived location of illusory conjunctions are the focus of chapter four.

CHAPTER 4: LOCATION PERCEPTION REVISITED

4.1 EXPERIMENT 8

4.1.1 INTRODUCTION

The results from experiments one and two provided no clear indication about the contribution that individual features make to the perceived location of illusory conjunctions. This ambiguity appeared to arise as a consequence of the data being averaged across all participants or averaged individually. While the results intimated that when data were averaged across participants, they showed that the perceived location was approximately at the midpoint between both contributing features conforming to the aggregate model (Hazletine *et al*, 1997), when individual participants' data were analysed, the source of the location information appeared to be either the target shape or distractor colour as suggested by Tsal & Lavie (1988) but with a bias ranging from approximately half to one target width (see Tsal & Baraket, 2005). It would seem from this that averaging the data across participants may have concealed the actual strategy being used. Similar problems were encountered by Townsend & Fifić (2004) in distinguishing between parallel and serial processing using a high-speed memory search. As far back as 1956, Estes had cautioned against the validity of inferences based on the distribution curves of averaged data (see also Hayes, 1953; Sidman, 1952).

A further problem was identified that directly resulted from not recording the position of stimulus strings in relation to the fixation point. As a consequence, it was impossible to establish whether the observed bias always moved in the direction of the fovea (e.g. Huttenlocher, *et al*, 1991; Kerzel, 2002a; Laeng, *et al*, 1998; Mateeff & Gourevich, 1983; Nelson & Chaiklin, 1980; O'Regan, 1984; van der Heijden *et al*, 1999) or was influenced by other salient objects in the display as suggested by both Hubbard (1995) and Kerzel (2002a), or indeed both.

In experiment three, a time delay of 2 sec was introduced post stimulus to determine whether an increase in bias would result when responses were made from short-term memory. If this was the case, it would provide a further indication that the perceived location was not comprised of an average of the target and distractor in that it has been demonstrated that increasing the time between the offset of the stimulus and making a response decision noticeably increased any bias that occurred (Werner & Diedrichsen, 2002). Results indicated that in the majority of cases, bias had indeed

increased with the time delay but again the data showed a high degree of variability. Coupled with the results from experiments one and two, there was a tentative indication that the location of an illusory conjunction may be sourced from a single feature but with variable amounts of bias and not, as Ashby *et al* (1996) proposed, sourced from an aggregate of location information from each contributing feature. However, at this stage no firm conclusions could be drawn.

Experiments four to seven focused on colour identification and indicated that colour perception is dependent on a number of factors. Most notably, if a single colour pops-out in a display, its colour is not always perceived accurately but may shift along the chromaticity spectrum in a tritan-like manner (Middleton & Holmes, 1949; Mollon & Polden, 1975). As some of the resultant colour shifts were very similar to other items used in the stimulus array, it is likely that the perceived location assumed by the researcher to belong to one stimulus item was allotted to another. This would have serious implications for the perceived location of illusory conjunctions.

Therefore the following experiments attempted to provide a clear differentiation between colour responses that were an accurate representation of a stimulus item and those that may be tritan-like so that a tritan-like response could not be mistaken with a colour present in the stimulus display. This differentation is critically important for assigning location responses to the correct object in the stimulus array for analysis. However, to provide a control, experiment eight uses a single target object.

4.1.2 METHOD

4.1.2.1 DESIGN

A full report paradigm was used in which the colour, shape and location for a single target only were to be reported. As the row of boxes used by Hazeltine *et al* (1997) and replicated in experiments one to three may have biased location responses, these were therefore omitted. The experiment was run over two days approximately one week apart providing a total of 288 experimental trials with 12 practice trials. These were divided into two groups of 144 trials, each with two groups of 6 practice trials. The independent variable was the position of the target in the visual field and the dependent variables were the types of errors made for identification of the target (colour and shape) and the exact perceived location of the target (in pixels). Apparatus and materials remained identical to those used for experiment seven as were the participants.

4.1.2.2 STIMULI

The size of each letter (0.45^o vertical by 0.53^o horizontal) and position within the visual field (4.66^o of visual angle to the left or right of fixation and extended 1.80^o vertically above or below the fixation point) remained the same as for experiment two. Thus the width of each letter was 17 pixels. The target letter was either a T or an X. Every colour used in the foregoing experiments was used and the CIE co-ordinates for each stimulus colour are detailed in table 4.1. A white background was used for those colours that had previously been presented on a white background (day one) and a grey background was used for those colours that had previously been presented on a grey background (day two).

Colour	**CIE *x* co-ordinate**	**CIE *y* co-ordinate**	**Luminance (cd/m^2)**
Red 1	0.61	0.35	4.27
Red 2	0.51	0.32	6.71
Blue (dark)	0.16	0.10	2.43
Blue 1	0.26	0.21	7.96
Yellow 1	0.45	0.50	18.91
Yellow 2	0.43	0.46	20.15
Green (dark)	0.38	0.53	3.36
Green	0.37	0.46	16.65
Orange 1	0.54	0.42	7.36
Orange 2	0.47	0.39	11.12
Magenta	0.30	0.17	6.09
Purple	0.32	0.23	7.63
Pink	0.36	0.29	10.08
Grey	0.34	0.34	4.60
Lime 1	0.41	0.46	14.51
Lime 2	0.45	0.50	10.00
Mauve	0.32	0.23	7.63
Turquoise 1	0.27	0.33	8.98
Turquoise 2	0.31	0.37	17.06
Aquamarine	0.27	0.34	3.71
Brown	0.51	0.44	3.11

Table 4.1: CIE (1931) chromacity co-ordinates plus luminance for each stimulus colour.

4.1.2.3 PROCEDURE

Participants were tested individually and the apparatus was arranged so that a viewing distance of approximately 70cm was achieved. Each practice trial was identical to the experimental trials except that the stimulus display was visible for 200

msecs. This was to allow participants to become accustomed to the task. While experimental exposure durations were controlled separately for each participant to reduce the rate of feature errors to approximately 10%. This was determined from the practice trials as follows: when error rates of less than 20% were recorded, the duration was reduced to 52 msec; when error rates fell between 20% and 40%, the duration was reduced to 104 msec; and when error rates greater than 40% were recorded, the duration was reduced to 156 msec. This resulted in stimulus durations bring set at 52 msec for each participant.

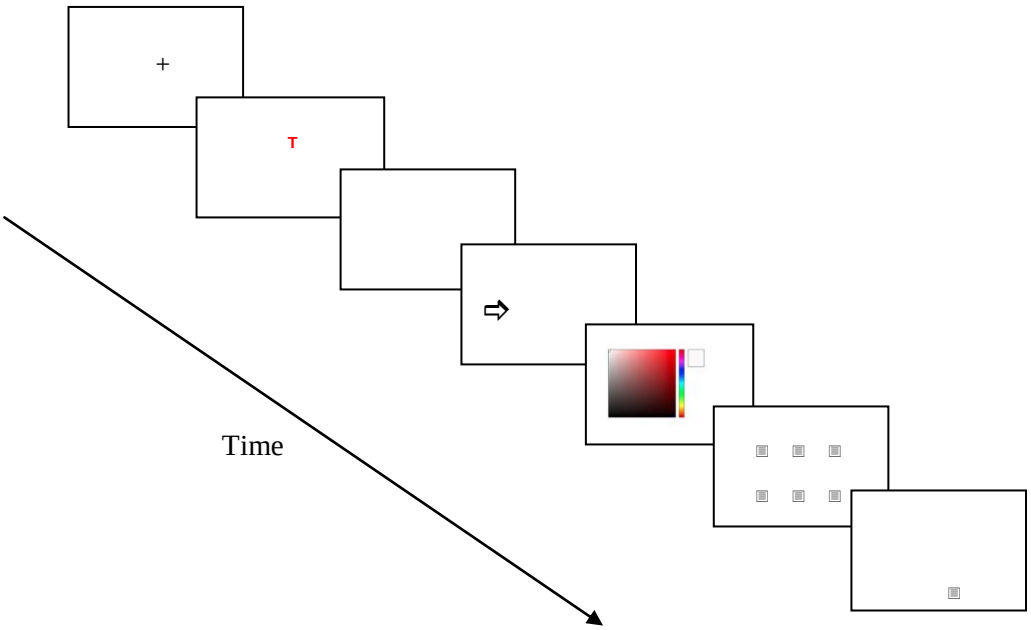


Figure 4.1: Representation of trial procedure (not to scale).

Each experimental trial proceeded as follows: first, a fixation cross appeared in the centre of the screen for 500 ms followed by the stimulus display that appeared for 52 ms. This was followed by a 52 msec blank screen. Next, a blank screen appeared on which participants were required to point and click the mouse on the location they had perceived the target to be. Following this, the colour palette became visible together with a box in which participants recorded whether the target letter they had seen was a T or an X. To record the colour they had perceived, participants were asked to move first the colour bar to select the colour, then to move a small white circle around the palette to record both saturation and luminance. Next, a screen was visible with two rows of three boxes to record how confident (confident, unsure and not confident), they were

regarding first the location and secondly the colour they had chosen. To give more control over the onset of each trial and to allow for rests when required, a further screen was presented containing a button to click when they were ready to begin a new trial. Participants were reminded that accuracy was most important and to take their time as speed was not an issue.

4.1.3 RESULTS

4.1.3.1 OBJECT IDENTIFICATION

Shape and colour responses were identified and the overall percentage means are detailed in table 4.2. Responses recorded as *letter incorrect* were low, amounting to 4% of the total trials. However, no *letter correct/ colour incorrect* responses were made with all colour shifts conforming to colours that would be expected for transient tritanopia. On 85% of trials, both the target letter and target colour were correctly identified (*letter correct/colour correct*). Responses where the target colour was reported to shift (*letter correct/target colour shift)* represented 11% of trials and is somewhat higher that that found for previous experiments excepting for the binary colour condition in experiment six.

	Target Colour	
Target Letter	**Correct**	**Colour Shift**
Correct	85.50 (5.47)	10.63 (4.06)
Incorrect	2.65 (1.59)	1.22 (0.98)

Table 4.2. Mean percentage (and standard deviation) of recorded identification responses.

Confidence ratings for *target letter correct* responses indicated that regardless of whether the perceived colour was reported to shift or not, confidence was extremely high indicating that tritan-like colour shifts were perceived as genuine perceptual phenomena. It can be seen from table 4.3 that responses were rated as 'confident' for 87% of *both correct* and 83% for *colour shift* reports.

	Confident	**Not Confident**
Colour Correct	86.70 (14.47)	13.30 (14.47)
Colour Shift	83.34 (18.60)	16.66 (18.60)

Table 4.3: Mean percentage (and standard deviation) confidence ratings expressed as a percentage for each target letter correct response category.

4.1.3.2 COLOUR SHIFTS

Targets that appeared to shift in the colour spectrum are shown in figure 4.4. All but turquoise were consistent with those found by Middleton & Holmes (1949) in that stimulus colours whose CIE co-ordinates place them above a line that moves from turquoise (487-490 nm) to orange (595-625 nm) will be perceived as more bluish. The one exception to this rule were reports that showed turquoise being perceived as blue. This, according to Middleton and Holmes (1947), should only occur when the stimulus colour CIE co-ordinate places it below the line when it will be perceived as less bluish (i.e. green). Indeed, such reports made up the greatest proportion of colour shifts (27%). However, while green to turquoise shifts amounted to 25% of reported colour shifts, only (7%) of blue responses recorded a tritan-like shift in the direction of turquoise. Tritan-like responses for yellow targets were perceived as white on 20% of these trials while orange targets were perceived as rose-purple on 16% and lime targets as bluish violet on 6%.

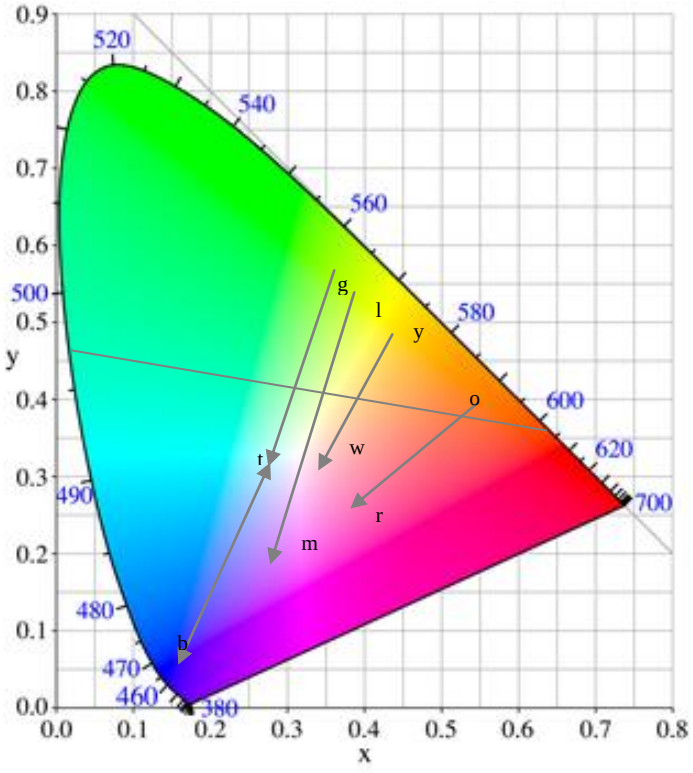


Figure 4.4: Approximate perceived colour shifts from their actual target colour plotted in CIE (1931) colour space.

4.1.3.3. OBJECT LOCATION

Target Letter	Target Colour	
	Correct	**Colour Shift**
Correct	10.59 (5.62)	11.54 (6.14)
Incorrect	18.85 (15.74)	26.39 (43.70)

Table 4.4: The mean (and standard deviation) of perceived location for all response categories for participants 2-8. Distance is a measure from the centre of the Target (0 pixels).

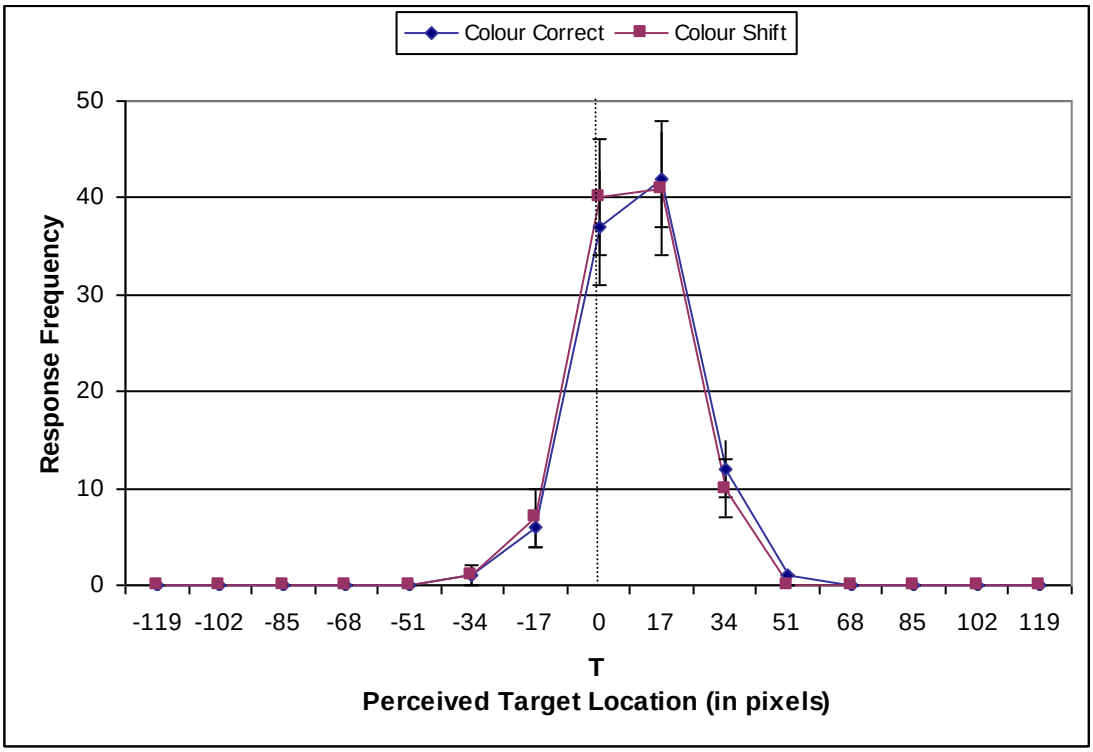


Figure 4.3: The percentage frequency for both correct and colour shift response categories (for participants 2-8 inclusive). These are shown as the distance in pixels from the actual location of the target. T represents the centre of the target position (0 pixels). Error bars = +/- 1 standard error.

Raw scores were recorded as the pixel dispersal from the centre of the target (0 pixels). As one participant reported the target's location to be almost 4 target widths away from its actual location and showed a considerable bias, their data was removed. Contrary to expectations, individual mean location responses showed no real movement from the target in the direction of fixation. Data were then normalised according to the direction of fixation with those location responses moving in the direction of fixation being given a positive value and those away from fixation, a negative value. Table 4.4 shows the overall mean perceived location for both response categories. The mean perceived location for colour shifts closely resembles that found when the target shape

and colour were both correctly identified. The mean perceived location of the target for the two letter correct response categories is only 2 and 3 pixels respectively from the edge of the target (see table 4.4). Data from both *letter correct* response categories were tested for normality using the Kolmogorov-Smirnov test and showed that both response categories were normally distributed ($D(7) = 0.21$, $p > 0.05$ and $D(7) = 0.15$, $p > 0.05$ respectively). However, pairwise comparisons between the actual target location and: the *letter correct/colour shift* responses ($t(6) = 3.05$; $p < 0.05$) and: *both correct* responses ($t(6) = 5.15$; $p < 0.05$) showed that the deviation from the centre of the actual target position was statistically significant in both cases indicating that some bias towards fixation was present.

4.1.3.4 LOCATION CONFIDENCE

The mean percentage of confidence ratings for both response categories can be found in table 4.5 As so few trials provided a location rating that were rated as anything other than 'confident', no separate analysis of confidently reported location responses was undertaken.

	Confident	**Not Confident**
Colour Correct	92.41 (6.45)	7.59 (6.45)
Colour shifts	87.32 (11.69)	12.68 (11.69)

Table 4.5 Mean (and standard deviation) confidence ratings expressed as a percentage for location in both letter correct response categories.

4.1.4 DISCUSSION

As would be expected with only a single stimulus object, despite the positioning of the target violating Bouma's bound (1970), *both correct* responses were extremely high amounting to 85% of all trials while responses recorded as colour shifts totalled only 3% of trials. For the remaining 12% of recorded responses, the target letter had been incorrectly identified. When tritan-like colour shifts had been accounted for, no *incorrect colour* responses were recorded for this experiment regardless of whether or not the target letter was correctly identified.

Analysis of those trials in which an apparent colour shift was perceived was consistent with the transient tritanopic reports found by Middleton & Holmes (1949). Green, yellow, orange and lime all showed shifts towards the violet end of the spectrum and blue showed shifts away. The shift from turquoise to blue however, only occurred

on those trials where a white background was used. Indeed, colour shifts were nearly twice as likely to be reported for colours presented on a white background than they were when the background was mid grey.

It was also apparent that for letter correct responses, when the item's colour shifted, the perceived location of that item was no different than when the colour was correctly identified. Indeed, results clearly indicate that the location of the target was perceived to be only 4 pixels from the edge of the item, albeit always in the direction of the fixation cross. This bias is less than that found by several researchers (e.g. Huttenlocher, *et al*, 1991; Kerzel, 2002a; Laeng, *et al*, 1998; Mateeff & Gourevich, 1983; Nelson & Chaiklin, 1980; O'Regan, 1984; van der Heijden *et al*, 1999). Individually, the mean location responses ranged from being centred over the target to ten pixels from the edge of the item towards fixation. However, when the target letter was incorrectly identified, the mean location showed an increase towards fixation of 11 pixels when the colour was correctly identified and 18 pixels when a colour shift was reported. Individual location responses also became highly variable. For those items where the colour bur not the shape had been correctly identified, mean location responses ranged from being centred over the target item to 26 pixels from the edge of the target towards fixation. For those items where neither the letter nor the colour was correctly identified, this variance increased from being 11 pixels in the opposite direction to fixation to 102 pixels towards fixation. These results may be an indication that it is both the shape and the colour of an item that determines the perceived location of that item as proposed by Hazeltine *et al* (1997) rather than either the shape or the colour as suggested by Tsal & Levi (1988).

4.2 EXPERIMENT 9

4.2.1 INTRODUCTION

Experiment eight clearly indicated that a single colour can be perceived to shift in a tritan-like manner. Further, while the perceived location of such responses showed an almost identical pattern to those responses where the colour was correctly identified for a single item, would this same pattern be evident for multi-item displays? This is important when trying to determine whether it is a single feature (colour or shape) or both features (colour and shape) that contribute to the perceived location of a complex object using the illusory conjunction paradigm. Experiments one to three had provided no clear evidence as to the featural contribution to the location of a complex object, so

experiment nine re-examines this question using a multi-item display but making careful use of colours. It is possible that in experiments one to three, colour responses attributed to items other than the target may, in fact, have been tritan-like responses providing specious location data. For example, in every colour string used for these experiments both orange and pink were present. However, when orange is seen in a tritan-like way, it is perceived as pink which would have been attributed to a different item in the display. As the distance between these colours could be between 34 and 68 pixels, this could have seriously compromised the location data. Thus, for this experiment, five stimulus colours were chosen that did not lay along tritan confusion lines so that each stimulus colour could in no way be confused with any reported tritan-like colour shift. In this way, it was hoped that the issues raised in chapter two might be resolved.

4.2.2 METHOD

4.2.2.1 DESIGN

The experimental design for this experiment was identical to that used for experiments one and two excepting that, as for experiment eight, a blank screen replaced the location boxes on the location response screen. A partial report paradigm was used in which the colour, shape and location for the target only were reported. As in experiment two, experiment nine used five stimulus items. Both the possible range of target shapes (T or X) and target colours (red, green or yellow) were known to participants prior to the start of the experiment. The dependent variables were the types of errors made for identification of the target (shape and colour) and the exact perceived location of the target (in pixels). Apparatus and materials remained identical to those used for experiment eight as were the participants.

4.2.2.2 STIMULI

Colour	CIE χ co-ordinate	CIE γ co-ordinate	Luminance (cd/m^2)
Red	0.61	0.35	4.27
Green	0.31	0.58	14.68
Yellow	0.45	0.50	18.68
Orange	0.54	0.42	7.36
Lime	0.37	0.56	14.76

Table 4.6 CIE (1931) chromacity co-ordinates plus luminance for each stimulus colour.

As in the display used for experiment two, letters subtended approximately 0.53° vertical by 0.45° horizontal (20 x 17 pixels) of visual angle at a viewing distance of 70 cm. Each letter was separated horizontally from its neighbour by approximately 0.90° of visual angle (34 pixels) centre to centre and position within the visual field (4.66° of visual angle to the left or right of fixation and extended 1.80° vertically above or below the fixation point) also remained the same. However, changes were made to the colour strings to ensure that only those colours that did not fall along the pseudo-isochromatic lines were used (see figure 4.4) resulting in only red, green, yellow, orange and lime being used. The CIE chromacity co-ordinates together with luminance are described for each colour in table 4.6

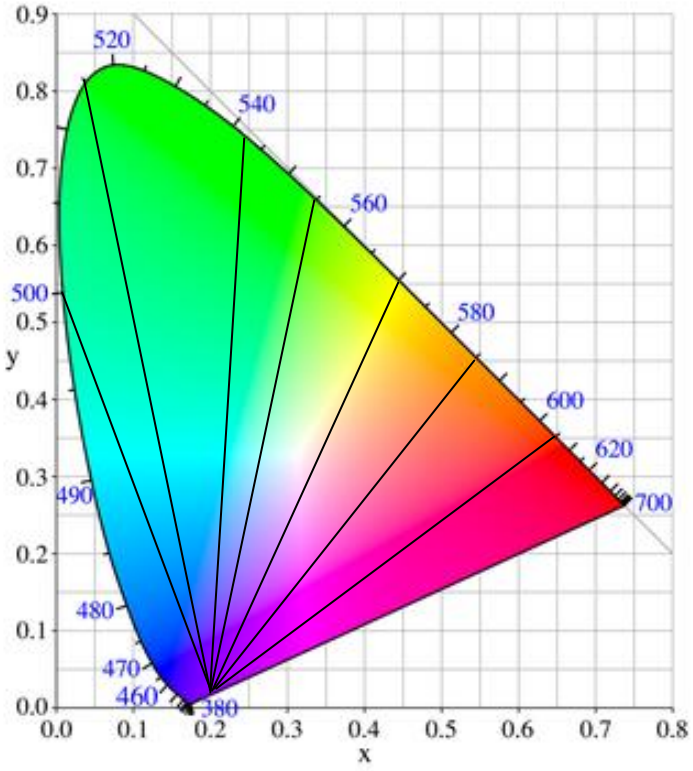


Figure 4.4: Depiction of the pseudo-isochromatic (indistinguishable) lines for tritanopes plotted in CIE (1931) colour space.

4.2.2.3 PROCEDURE

Participants were tested individually and the apparatus was arranged so that a viewing distance of approximately 70cm was achieved. Instructions were provided as to the task requirements and any questions raised were answered only if the naivety of the participant remained intact. The experiment was run over two days and consisted

of one block of 12 practice trials followed by 288 experimental trials on the first day repeated on the second day giving a total of 576 experimental trials. Each practice trial was identical to the experimental trials except that the stimulus display was visible for 200 msecs. This was to allow participants to once again become accustomed to the task. While experimental exposure durations were controlled separately, this resulted in experimental stimuli durations again being presented for 52 msec for each participant .

Experimental trials proceeded in a similar fashion to that of experiment eight: first, a fixation cross appeared in the centre of a white screen for 500ms. This was succeeded by the stimulus display which appeared for 52 ms, also on a white screen and was followed by a 52 msec blank white screen. Next, a blank white screen appeared on which participants were required to point and click the mouse on the location at which they had perceived the target. Following this, the colour palette became visible where participants recorded the hue, saturation and brightness of the target and a box in which participants were to record what target letter they had seen. Next, a screen was visible with two rows of three boxes to record how confident (confident, unsure and not confident), they were regarding first the letter and secondly the colour they had chosen. Finally, a screen was presented containing a button to click when the participant was ready to begin a new trial.

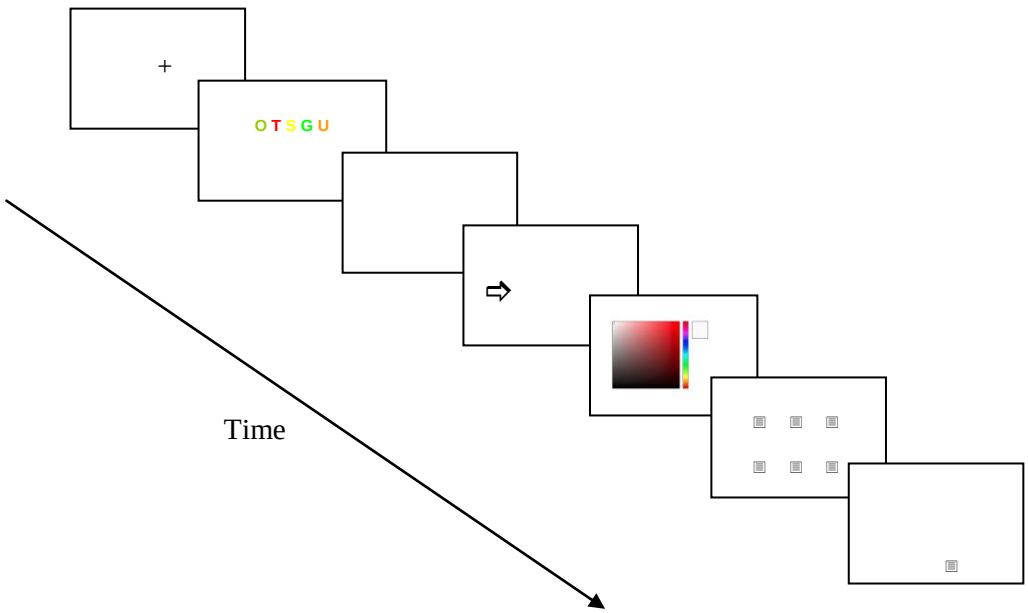


Figure 4.5: Representation of trial procedure (not to scale).

4.2.3 RESULTS

4.2.2.3 OBJECT IDENTIFICATION

Colour and shape responses are recorded as the mean percentage of trials across participants and are detailed in table 4.7. Responses recorded as *letter incorrect* were low, amounting to 7% of the total trials. On only 48% of trials were both the target letter and target colour correctly identified (*both correct*) but this may be due to the colour strings which comprised colours that did not lay on tritan lines (red, orange, yellow, lime and green). This also resulted in a high proportion of trials that were reported as illusory conjunctions. These responses fell into three categories: where the colour of the item positioned to the immediate right of the target was reported (*letter correct/distractor colour:* NTNNN); where the non-target colour immediately to the left of the target was reported (*letter correct/distractor*: NTNNN); where the non-target colour immediately to the right of the distractor was reported (*letter correct/adjacent distractor*: NTNNN) and where the non-target colour in position five was reported (NTNNN). Collectively, these represented 42% of trials. As expected, participants also appeared to confuse the target colour with the distractor colour far more frequently than they mistook the colours of the items in any other position. When *letter correct/distractor colour* responses were combined with the *letter correct/distractor* responses, they provided a strong adjacency effect. This was confirmed by a pairwise comparison between the combined reports of *letter correct/distractor* and *letter correct/adjacent target* with the combined reports of *letter correct/adjacent distractor* and *letter correct/non-target*: ($t(7) = 6.61$; $p<0.01$).

Colour	Normalised Position	Target Letter	
		Correct	Incorrect
Target	NTNNN	47.75 (10.50)	1.35 (1.61)
Distractor	NTNNN	20.56 (5.95)	1.21 (1.01)
Adjacent target	NTNNN	8.98 (5.75)	1.35 (1.10)
Adjacent distractor	NTNNN	4.90 (2.88)	0.54 (0.58)
Non-target	NTNNN	7.67 (4.15)	1.77 (1.22)
Colour shift: target	NTNNN	2.21 (3.08)	0.04 (0.08)
Colour shift: distractor	NTNNN	0.27 (0.41)	0.08 (0.24)
Colour shift: adjacent target	NTNNN	none	0.19 (0.40)
Colour shift: adjacent distractor	NTNNN	none	0.04 (0.08)
Colour shift: non-target	NTNNN	0.46 (0.34)	0.19 (0.35)

Table 4.7: Mean percentage (and standard deviation) of recorded identification responses.

Responses recorded as colour shifts represented only 3% of all *target letter correct* trials and were categorised into five different types, each relating to a position of an item in the stimulus string. Responses where the target colour was reported as a tritan-like change (*letter correct/target colour shift)* represented 2% of trials. Colour shifts for both the distractor colour (*letter correct/distractor colour shift)* and non-target colour (*letter correct/non-target colour shift)* each represented less than 1% of the total trials. No colour shifts were recorded for either the colour adjacent to the target (*letter correct/distractor colour shift)* or for the colour adjacent to the distractor (*letter correct/adjacent distractor colour shift).*

4.2.3.2. IDENTIFICATION CONFIDENCE

Confidence ratings indicated that regardless of the type of colour error, confidence was extremely high that the colour perceived was that of the target. It can be seen from table 4.8 that responses were rated as "confident" for 86% of both correct reports and between 68% and 80% for all illusory conjunction responses. Colour shift responses were rated just as confidently except where the distractor colour had been perceived to shift. For these reports, participants appeared to be confident on every occasion that the colour they had perceived was that of the target. As no incorrect colour responses were recorded, it is extremely likely that genuine perceptual phenomena were perceived in all cases.

Letter Correct	Confident	Unsure	Not Confident
Colour			
Correct	85.59 (13.55)	5.14 (4.38)	9.23 (10.35)
Distractor	79.04 (20.71)	8.93 (8.29)	12.03 (13.23)
Adjacent target	80.26 (23.21)	10.83 (10.96)	11.18 (10.53)
Adjacent distractor	79.57 (20.64)	16.31 (18.89)	8.54 (10.46)
Non-target	67.61 (25.89)	13.40 (14.41)	17.04 (15.09)
Colour shift: target	77.84 (36.48)	26.02 (35.88)	1.14 (3.21)
Colour shift: distractor	100.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Colour shift: adjacent target	83.33 (28.87)	4.17 (7.22)	12.50 (21.65)
Colour shift: adjacent distractor	83.33 (23.57)	11.11 (15.71)	5.56 (7.86)
Colour shift: non-target	74.29 (44.29)	25.71 (44.29)	0.00 (0.00)

Table 4.8: Mean (and standard deviation) confidence ratings expressed as a percentage for each target letter correct response category.

4.2.3.3. OBJECT LOCATION

Raw scores were recorded as the pixel dispersal from the centre of the target (0 pixels). These were then analysed to determine whether the direction of fixation had influenced location responses. However, unlike the data for the previous

experiment, no such bias was apparent. Data were next normalised by subtracting the perceived location from the actual target location to give a ± result in pixels. Negative values represent location reports that moved away from the target in the opposite direction to fixation and positive values those response locations that moved from the target towards fixation. Table 4.9 shows the overall mean perceived location for each of the ten response categories.

A series of planned comparisons with Bonferroni correction (decreasing the critical p value to 0.008), were conducted after data were tested for normality using the Kolmogorov-Smirnov test for six of the ten response categories. Colour shift responses, excepting for those relating to the target, provided so little data that statistical analysis could not be performed. However, of the remaining categories, *only both correct* and *letter correct/distractor colour* responses provided sufficient data to form reasonably sound conclusions and extreme caution should be used to form any but highly tentative conclusions for the remaining response categories. Nevertheless, of those response categories analysed, all but *letter correct/non-target colour* were shown to be normally distributed.

Colour	Normalised Position	Target Letter	
		Correct	Incorrect
Correct	NTNNN	0.38 (4.73)	8.72 (30.56)
Distractor	NTNNN	23.55 (9.46)	37.14 (34.26)
Adjacent target	NTNNN	-21.11 (12.52)	-2.35 (29.30)
Adjacent distractor	NTNNN	48.84 (19.48)	60.65 (25.72)
Non-target	NTNNN	48.51 (32.73)	58.72 (69.79)
Colour shift: target	NTNNN	5.31 (24.80)	16.50 (34.65)
Colour shift: distractor	NTNNN	0.99 (24.32)	3.50 (0.00)
Colour shift: adjacent target	NTNNN	18.75 (34.21)	51.29 (45.08)
Colour shift: adjacent distractor	NTNNN	59.45 (7.86)	88.50 (3.54)
Colour shift: non-target	NTNNN	21.32 (42.09)	37.60 (0.00)

Table 4.9: The mean percentage (and standard deviation) of perceived location for each response category. The distance is a measure from the centre of the Target (0 pixels).

The overall mean location for both letter and colour correct responses (*both correct*) was perceived to be on the actual target position. This was confirmed by the pairwise comparison ($t(7) = -0.23$, $p>0.008$) showing that there was no significant deviation away from the actual target position. Similarly, when a tritan-like colour shift for the target colour was reported, the mean overall perceived location was centred over the actual target (*letter correct/colour shift target*). Again, a pairwise comparison confirmed that the perceived location was not significantly removed from the target position ($t(7) = -0.60$, $p>0.008$). For the four illusory conjunction response categories

the picture is somewhat different. When the colour of the item directly to left of the target was reported (*letter correct/distractor*), the perceived location was centred at the midpoint between the item and the target. Again this was confirmed by a pairwise comparison ($t(7) = 4.77$; $p < 0.008$) showing that the mean perceived location for this category was significantly removed from the actual target location. When the colour of the item directly to the right of the target was reported (*letter correct/distractor colour),* the location was perceived to be on this item rather than the target. The pairwise comparison showed that the mean perceived location when the distractor colour had been perceived was significantly removed from the actual target position ($t(7) = -7.02$, $p < 0.008$).

For the remaining two categories which were not adjacent to the target *(letter correct/adjacent distractor; letter correct/non-target*), the locations for both response categories were perceived to be between the distractor and the adjacent distractor items. This places both close to the midpoint of the entire stimulus string. In both cases, pairwise comparisons confirmed that the perceived location was significantly removed from the actual target position ($t(7) = -7.16$, $p<0.008$; $t(7) = -4.19$, $p<0.008$ respectively). Thus, the mean location of an item as well as reported tritan-like target colour shifts all appeared to be perceived either over the target shape or over the item's colour, except for non-adjacent illusory conjunction responses *(letter correct/adjacent distractor; letter correct/non-target*) which were both perceived to be at the midpoint of the whole stimulus display.

The perceived location of the four remaining tritan-like colour categories (*letter correct/colour shift adjacent target; letter correct/colour shift distractor; letter correct/colour shift adjacent distractor; letter correct/colour shift non-target)* were not statistically analysed although, in each case, it appeared that for these types of responses, the location could be perceived anywhere within the stimulus string.

Figures 4.6, 4.7 and 4.8 show the response categories divided into those illusory conjunctions that were adjacent to the target, those that were not and those for a target colour reported as a tritan-like colour shift. In each case, the overall mean perceived location does not reflect the distribution of responses. Examination of figure 4.6 indicates that the majority of responses are located within two target widths of the actual position of the target although a small proportion are perceived to be anywhere within the area of the stimulus array. Similarly, when the colour from the item positioned to the left of the target was reported (*letter correct/distractor*), the perceived

location peaked over this item but again a distribution of two target widths was noted. In contrast, when the distractor colour was reported, (*letter correct/distractor colour*), no peak was observed either around the target or the distractor, rather all responses showed a distribution that spanned almost the entire width of the stimulus array.

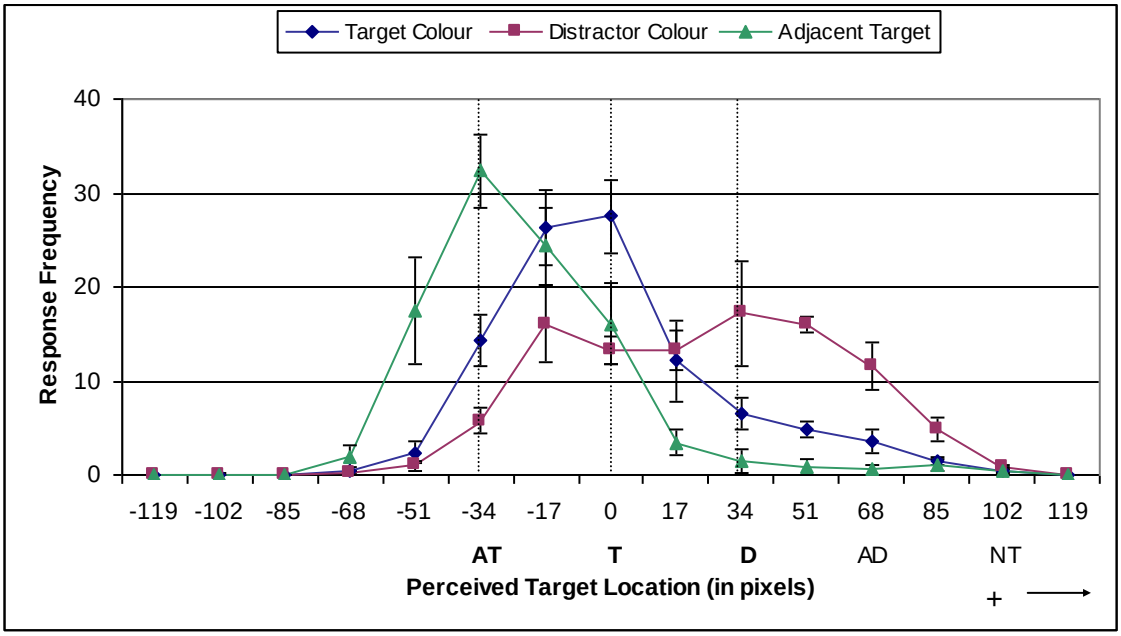


Figure 4.6: The percentage frequency for both correct, letter correct/distractor colour and letter correct/adjacent target confident response categories shown as the distance in pixels from the actual location of the target. T represents the centre of the target position (0 pixels) with the four non-targets shown at their respective locations (-34, 34, 68 and 102 pixels respectively). Error bars = +/- 1 standard error.

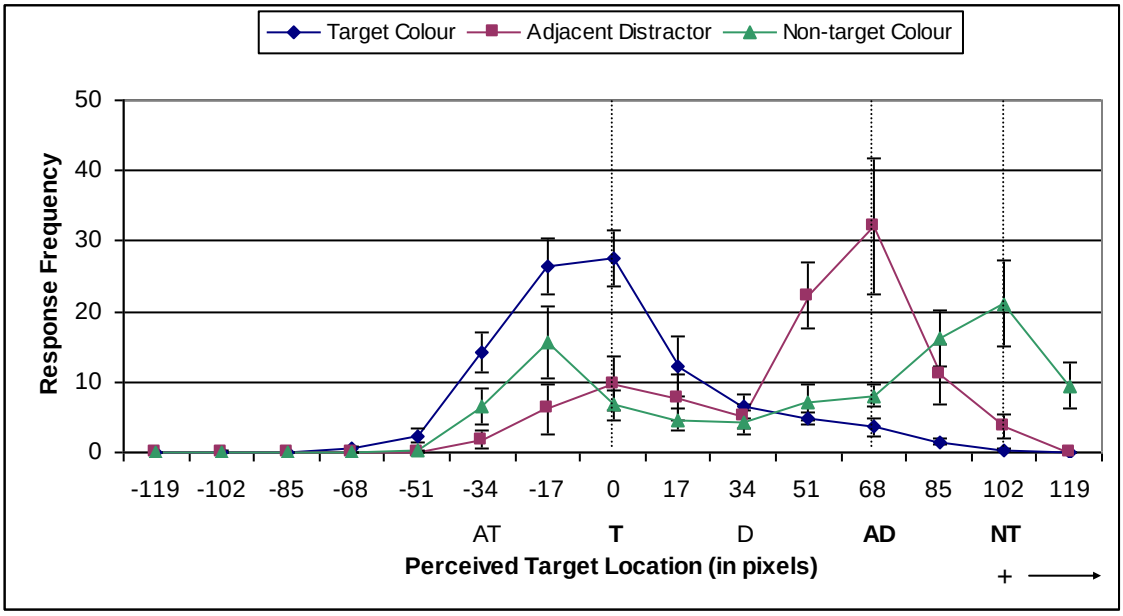


Figure 4.7: The percentage frequency for both letter and colour correct, letter correct/adjacent distractor colour and letter correct/non-target colour response categories. These are shown as the distance in pixels from the actual location of the target. T represents the centre of the target position (0 pixels) with the four non-targets shown at their respective locations (-34, 34, 68 and 102 pixels from the target respectively). Error bars = +/- 1 standard error.

For both response categories in which the reported colour was from an item not adjacent to the target (*letter correct/adjacent distractor; letter correct/non-target*), peaks were apparent both around the target shape and around the colour of the item reported (figure 4.7).

Examination of figure 4.8 indicates the distribution when a colour shift is reported. This shows that the perceived location was just as likely to be reported around the item to the left of the target than at the actual target position but again, with a proportion of responses that spanned the rest of the stimulus array.

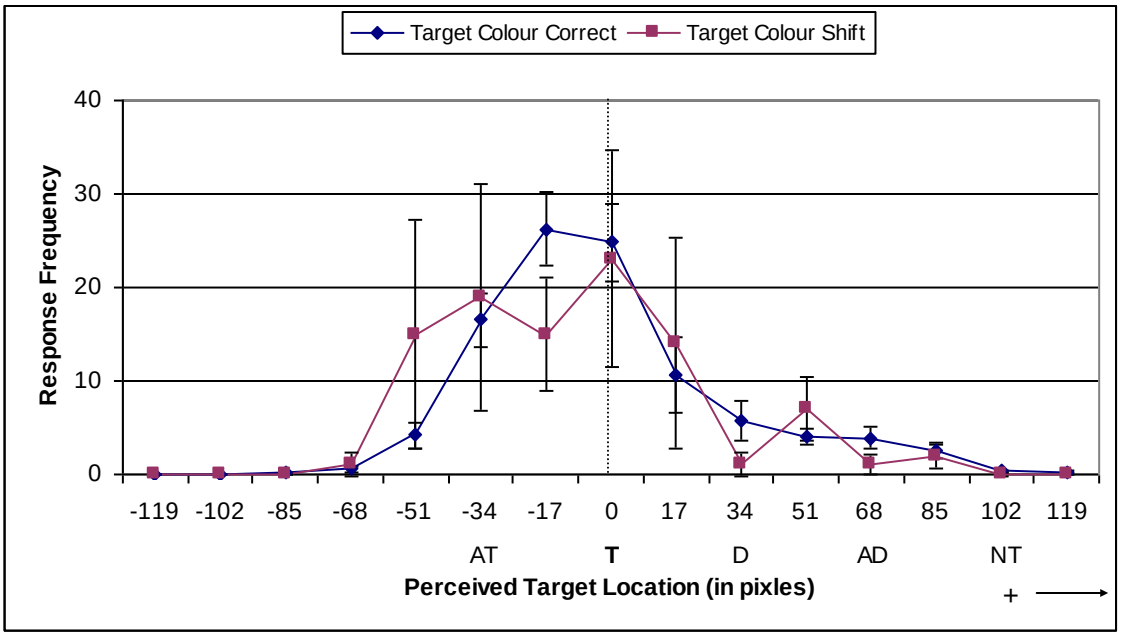
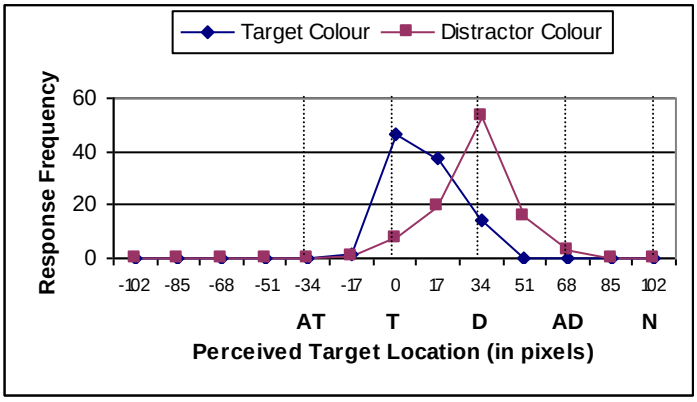


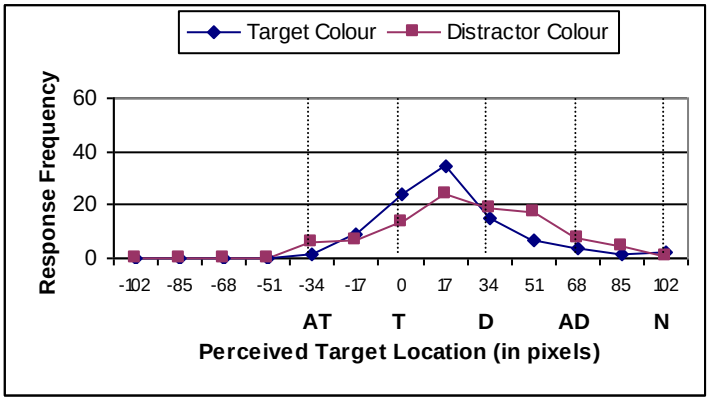
Figure 4.8: The percentage frequency of responses for both correct and letter correct/target colour shift responses. These are shown as the distance in pixels from the actual location of the target. T represents the centre of the target position (0 pixels). Error bars = +/- 1 standard error.

However, the overall means do not adequately reflect individual participants' responses and as a result of the lack of bias towards fixation, a detailed examination of the data indicated that a number of participants were confusing red with orange and green with lime resulting in the incorrect stimulus item being designated as the response item and providing spurious location results. For example, when each participant's data for *both correct* and *target letter correct/distractor colour* response categories were plotted (figures 4.9 a to h), it can be seen that even allowing for location uncertainty the variability between participants was high ranging from one and a half target widths to three. For at least six participants, the perceived location encompassed other non-target items. A re-examination of responses for experiment eight showed no such problem, nor did the pre-tests conducted prior to experiment five. Therefore, participants were

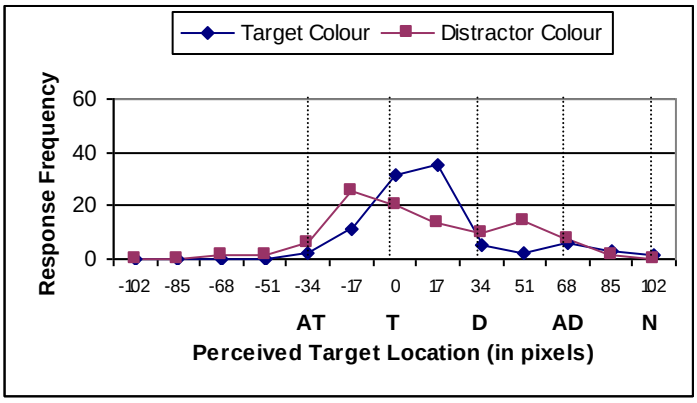
tested for their discrimination between red/orange and green/lime in multi-item displays. Results indicated that six of the eight participants did, albeit only on some trials, find it difficult to differentiate between either one or both of the colour sets in briefly presented displays. Under the circumstances, no further location analysis could be usefully performed and the experiment was redesigned to take account of this finding.



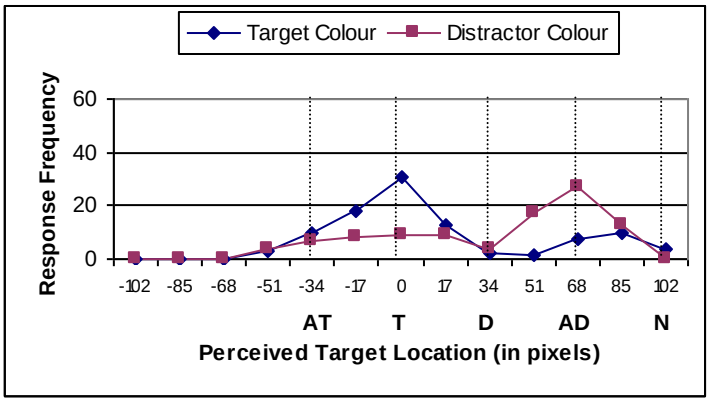
4.9a: participant 1



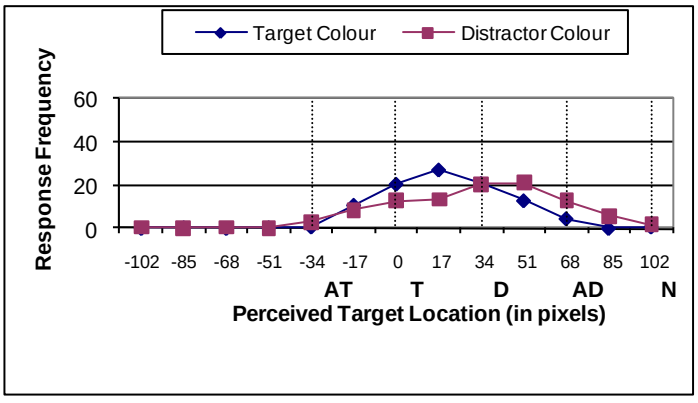
4.9b: participant 2



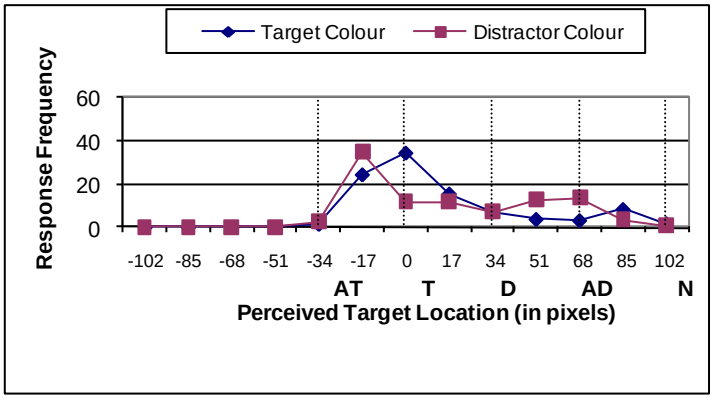
4.9c: participant 3



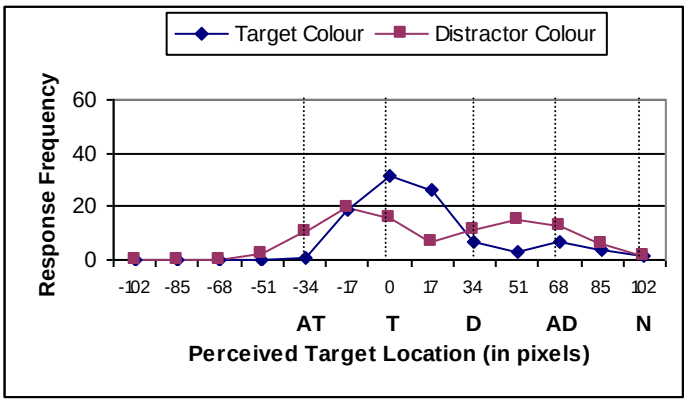
4.9d: participant 4



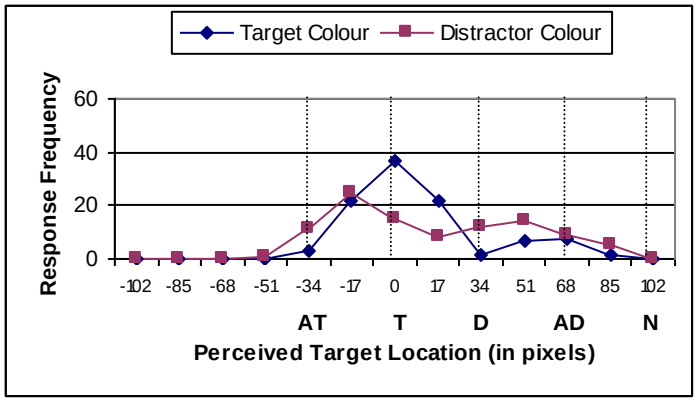
4.9e: participant 5



4.9f: participant 6



4.9g: participant 7



4.9h: participant 8

4.2.4 DISCUSSION

As found for experiments seven and eight, the frequency of incorrect target letter identification responses for experiment nine was comparable at 7%. No *incorrect colour* responses were again recorded for this experiment whether the target letter was correct or not. This can probably be attributed to the identification and inclusion of those responses that reported a tritan-like colour shift which would normally have been classed as incorrect.

On only 48% of trials were both the shape and the colour correctly identified. This reduction resulted in a concomitant increase (42%) in the number of illusory conjunction responses. Where a colour shift was reported, it was most often associated with a tritan-like shift in the target colour. In total, these represented 3% of all trials with the vast majority (74%) relating to green being perceived as turquoise or, to a much lesser extent, as blue.

While no incorrect colour responses were recorded, indicating that the illusory conjunction responses did not result from guessing, the perceived location for all response categories, including those where the target had been correctly identified, showed a wide variance, approximating two target widths either side of the perceived target. Indeed, for the majority of the response categories, the data were shown to be non-normally distributed and further analysis indicated that some stimulus colours had been incorrectly categorised. For example, examination of individual data points indicated that the two binary colours (lime and orange) may be being confused with a unitary colour of which it forms a part (lime with green and orange with red). While such confusions might have resulted from the colours being indistinguishable, as both lime and orange were intermediate binaries, this seemed unlikely and was subsequently

found to be the case. When participants were retested with briefly presented displays consisting of either red and orange or green and lime items, six of the eight consistently confused the two. The red/orange confusion is observed for tritanopes where unique red (700) is perceived as orange (595-625). However, this is surprising given Middleton & Holmes (1949) finding that transient tritanopia behaves differently in that red and orange do not appear to shift. This shift, however, was not observed for single item displays in experiment eight, although some individual responses were reported very close to their borders as per the pre-test conducted prior to experiment five. While the current experiment was presented parafoveally, subsequent testing demonstrated that this did occur and such sensitivity may extend to this area. It has also been shown that male observers can perceive green as lime although this does not appear to be the case for female observers (Volbrecht, Nerger & Harlow, 1997). In the current experiment, only male participants showed a confusion between green and lime. As a result, it was not, therefore, surprising that location responses did not fall within the expected parameters as defined by experiment eight. To eliminate any possibility of lime/green and orange/red confusions, a further experiment was conducted in which both lime and orange were omitted from the stimulus display.

4.3 EXPERIMENT 10

4.3.1 INTRODUCTION

The results from experiment nine indicated that some colour data were being incorrectly categorised. For example, for the majority of participants, on some trials the location for a response correctly identifying a red target was reported on or close to the actual location of not the red target but an orange non-target item. Similar responses were found for green and lime. This resulted in the location reports being attributed incorrectly and so seriously affecting the reliability of the data. To rectify this, while still using colours that did not fall along tritan lines (red, green and yellow), the stimulus displays had to be reduced from five to three items. This was to ensure that the location responses could be attributed to the item that had actually been perceived while also ensuring that any tritan-like colour responses could not be confused with any of the stimulus colours.

4.3.2 METHOD

4.3.2.1 DESIGN

Experiment ten was identical to experiment nine in all respects except that the number of trials was reduced from 600 to 150 and the colours used in the stimulus display excluded orange and lime, reducing the number of colours and hence stimulus items from five to three. No changes were made to the participants, apparatus, materials or the experimental procedure.

4.3.2.2 STIMULI

Colour	CIE χ co-ordinate	CIE γ co-ordinate	Luminance (cd/m^2)
Red	0.61	0.35	4.27
Green	0.31	0.58	14.68
Yellow	0.45	0.50	18.68

Table 4.10: CIE (1931) chromacity co-ordinates plus luminance for each stimulus colour used.

The target letters remained the same (T or X) and the two non-target letters were again randomly chosen from the following letters: OSGCU. The target letter was randomly assigned to either position one, two or three. Each colour string was comprised of a random combination of red, green and yellow (see table 4.10). While both possible target letters (T or X) were known prior to the commencement of the experiment, this was not the case for the target colour. Positioning of the stimuli in the visual field remained identical to experiment nine but the visual angle for the complete stimulus string was reduced to 2.25^o at a viewing distance of 70 cm.

4.3.3 RESULTS

4.3.3.1 OBJECT IDENTIFICATION

Colour	Target Letter	
	Correct	**Incorrect**
Target	62.93 (13.85)	2.34 (1.70)
Distractor	19.36 (12.78)	4.43 (3.91)
Non adjacent target	1.39 (1.44)	1.82 (1.62)
Colour shift: target	5.30 (4.00)	0.09 (0.25)
Colour shift: adjacent target	1.48 (1.80)	0.43 (0.64)
Colour shift: non adjacent target	None	0.35 (0.52)

Table 4.11: Mean percentage (and standard deviation) of recorded identification responses.

Six colour response types were identified and the overall percentage means are detailed in table 4.11. Marginally more responses were recorded as *letter incorrect* (9%) than in experiment nine (7%). However, in experiment nine, no *letter correct/colour incorrect* responses were made at all. On 63% of trials, both the target letter and target colour were correctly identified (*letter correct/colour correct*). Responses categorised as illusory conjunctions fell into two categories: those colours from the items directly to the left or the right of the target (*letter correct/adjacent colour*); and those colours that were not adjacent to the target (*letter correct/colour not adjacent*). These totalled 20% of all trials (19% and 1% respectively). As expected, participants reported the colour of the items that were adjacent to the target significantly more frequently than they reported the colour of the item that was not ($t(7) = 3.93$; $p<0.05$.

Responses recorded as colour shifts represented only 7% of trials in total and were categorised into three different types. Responses where the target colour was reported to shift (*letter correct/target colour shift)* represented 5% of trials. On only 1% of trials, the colour of the item adjacent to the target (*letter correct/adjacent colour*) was perceived to shift. There were no responses in which the item that was not adjacent to the target (*letter correct/colour not adjacent*) was perceived to shift. However, throughout these results, a great deal of caution needs to be used when interpreting these data due to the very small number of data points recorded for all but the *both correct* and *letter correct/adjacent colour* responses.

4.3.3.2 IDENTIFICATION CONFIDENCE

Colour	Confident	Unsure/Not Confident
Correct	89.69 (10.98)	10.18 (10.94)
Adjacent target	72.76 (17.78)	27.24 (17.78)
Non adjacent target	61.90 (45.86)	38.10 (45.86)
Colour shift: target	59.38 (49.89)	40.63 (49.89)
Colour shift: adjacent target	60.00 (56.57)	40.00 (56.57)
Colour shift: non adjacent target	None	None

Table 4.12. Mean (and standard deviation) confidence ratings expressed as a percentage for each target letter correct response category.

Confidence ratings were analysed to determine what proportion of illusory conjunction responses might be attributable to guessing. As so few 'unsure' responses were recorded, these were amalgamated with 'not confident' responses and can be found in table 4.12. This shows that responses were rated as 'confident' for 90% of

those trials where the target was correctly identified. While 73% of the adjacent colour responses were reported as 'confident' (*letter correct/adjacent colour*), only 62% of those not adjacent to the target were (*letter correct/colour not adjacent*). In this experiment, fewer illusory conjunction responses were rated as 'confident' (73%) than when the target was correctly identified (90%). However, as no incorrect colour responses were recorded, it is unlikely that illusory conjunction responses could be attributed to guessing and can therefore be seen as genuine perceptual phenomena. When an item's colour was perceived to shift, the number of 'confident' reports was very similar to that found for the non-adjacent target category (59% for *letter correct/colour shift target;* 60% for *letter correct/ colour shift adjacent target*).

4.3.3.3. OBJECT LOCATION

Raw scores were again recorded as the pixel dispersal from the centre of the target (0 pixels). As in experiment eight, the direction of fixation again consistently appeared to influence location responses and data were therefore normalised by subtracting the perceived location from the actual target location to give a ± result in pixels. Negative values represent location reports that moved away from the target in the opposite direction to fixation and positive values represent those response locations that moved from the target towards fixation. Table 4.13 shows the overall mean perceived location for each of the six possible response categories.

Colour	**Normalised Position**	**Target Letter**	
		Correct	**Incorrect**
Correct	TNN	14.15 (11.02)	14.70 (51.87)
Adjacent Target	TNN	24.97 (14.39)	27.32 (22.68)
Not Adjacent Target	TNN	35.01 (17.08)	50.56 (37.33)
Colour Shift: Target	TNN	29.75 (27.	30.00 (0.00)
Colour Shift: Adjacent Target	TNN	34.22 (25.74)	33.00 (12.76)
Colour Shift: Not Adjacent Target	TNN	none	-16.03 (18.19)

Table 4.13: The mean (and standard deviation) of perceived location for each response category. The distance is a measure from the centre of the target (0 pixels).

A series of planned comparisons with Bonferroni correction (decreasing the critical p value to 0.0125), were conducted after data were tested for normality using the Kolmogorov-Smirnov test. Only *both correct*, *letter correct/adjacent colour*, *letter correct/non-adjacent colour* and *letter correct/colour shift target* were analysed

due to a lack of data. All four tested response categories were shown to be normally distributed.

The mean overall location of both letter and colour correct responses (*both correct*) was shown to be significantly outside the area encompassed by the actual target position (17 pixels). This was confirmed by a pairwise comparison between *both correct* responses and the actual target position ($t(7) = 3.97$, $p<0.02$). When a tritan-like colour shift was reported for the target colour (*letter correct/colour shift target*), the mean perceived location shifted towards the centre of the stimulus string by over one target width. The target colour shift category also showed that the perceived location was also significantly different from the actual target position ($t(7) = 3.70$, $p<0.02$).

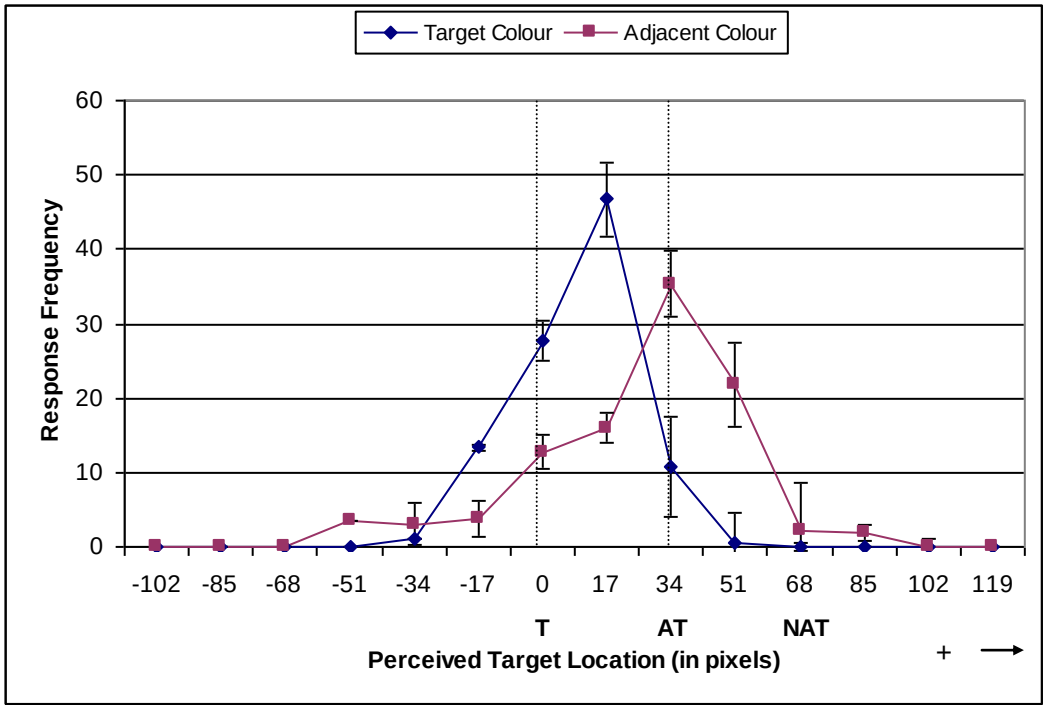


Figure 4.10: The percentage frequency for both correct and letter correct/adjacent colour categories. These are shown as the distance in pixels from the actual location of the target. T represents the centre of the target position (0 pixels) with the two non-targets shown at their respective locations (34 and 68 pixels). Error bars = +/- 1 standard error.

Illusory conjunction reports for those items adjacent to the target (*letter correct/adjacent colour*) showed that the perceived location was also significantly removed from the actual target location and positioned over the colour of the item perceived ($t(7) = 5.84$, $p<0.02$), indicating that it was colour that provided the location information. A similar pattern was observed for illusory conjunctions comprised of a colour from the item that was not adjacent to the target (*letter correct/non-adjacent colour*) which was also confirmed by a pairwise comparison indicating that the

perceived location was significantly removed from that actual target position ($t(6) = 5.01$, $p < 0.02$).

Examination of figure 4.10 indicates that when the target was correctly identified, the perceived location for the majority of trials was centred around the target with a directional bias of up to one and half target widths. This is comparable to that found for experiment eight. Similarly, when a colour from an item adjacent to the target was reported, (*letter correct/adjacent colour*), location responses showed a distribution that mainly centred over the adjacent colour, but with a non-directional bias of approximately two target widths. This would indicate that for the majority of trials, it was the colour providing the location information but on some trials, it was the target shape that influenced responses.

Similarly, when figure 4.11 is examined, the perceived location of the non-target item in position three clearly shows that for the majority of trials, it is the colour that provides the location information with the remaining being provided by the target shape. As for correctly identified targets, the same one and a half target width bias towards fixation was found. In sum, there appears to be a clear indication that it is a single feature that provides the location information.

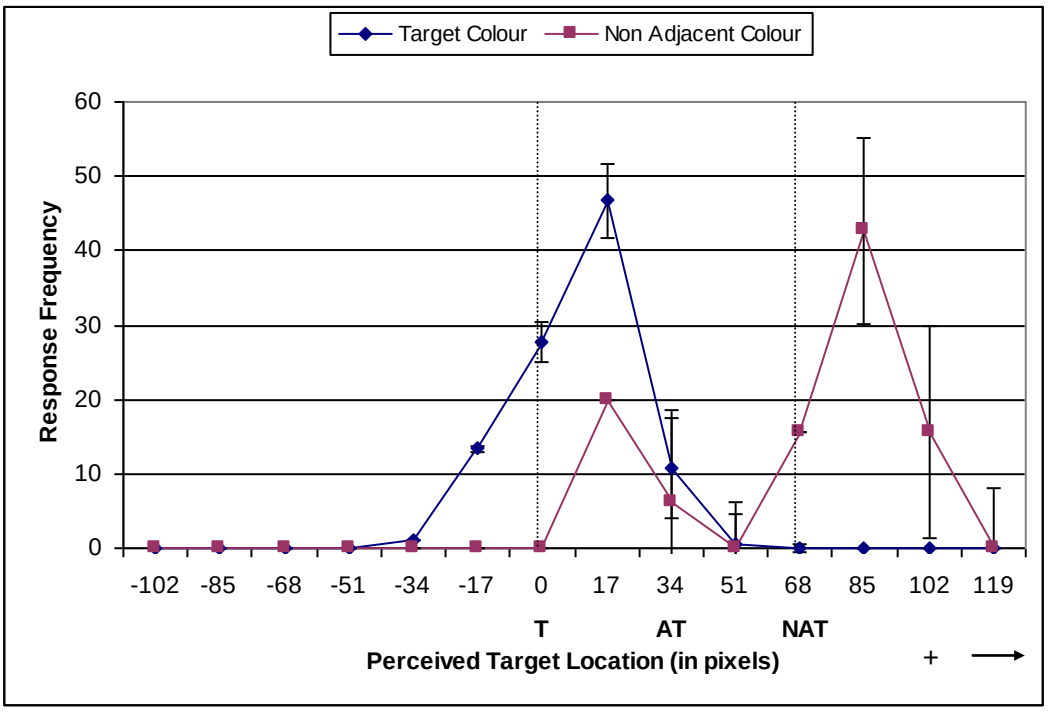


Figure 4.11: The percentage frequency for both correct and letter correct/non-adjacent colour categories. These are shown as the distance in pixels from the actual location of the target. T represents the centre of the target position (0 pixels) with the two non-targets shown at their respective locations (34 and 68 pixels). Error bars = +/- 1 standard error.

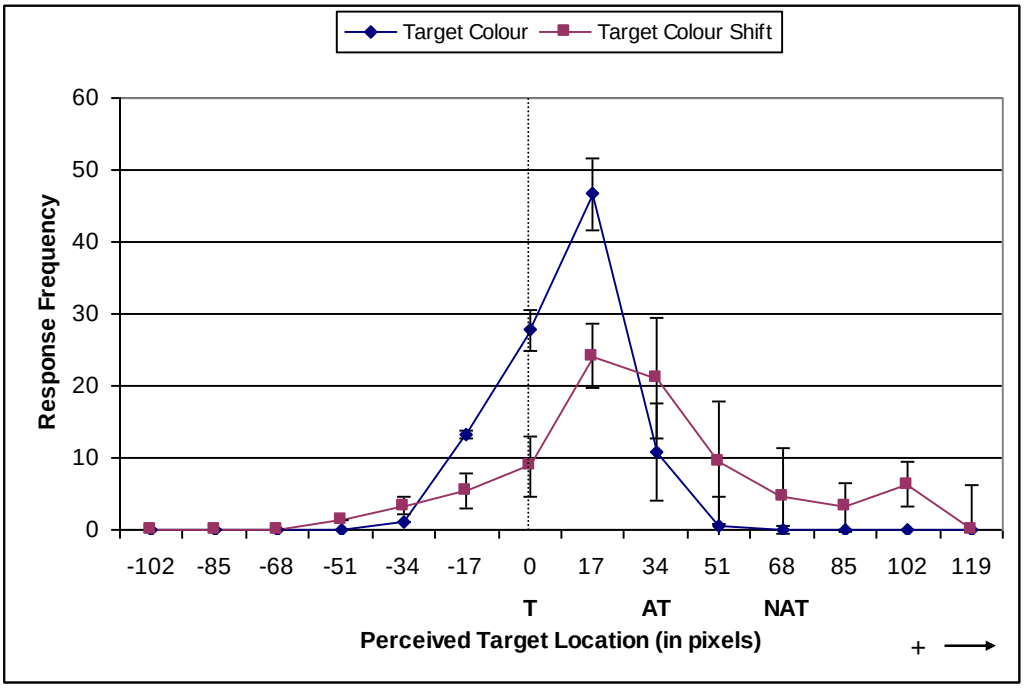


Figure 4.12: The percentage frequency for both letter and colour correct and letter correct/target colour shift response categories. These are shown as the distance in pixels from the actual location of the target. T represents the centre of the target position (0 pixels) with the two non-targets shown at their respective locations 34 and 68 pixels from the target respectively). Error bars = +/- 1 standard error.

There is also an indication that fixation exerts an influence resulting in a reasonably high but consistent degree of location uncertainty. Examination of target colour shift responses in figure 4.12, indicates that when a colour is perceived in a tritan-like manner, the perceived location becomes far more uncertain. This is contrary to that found for experiment eight.

4.3.3.4 LOCATION CONFIDENCE

Confidence ratings indicated that regardless of the type of error, participants were confident that they had correctly perceived the location of the target. As so few 'unsure' responses were recorded, these were amalgamated with 'not confident' responses and can be found in table 4.14. Only *both correct and letter correct/adjacent colour* confident responses provided enough data for analysis and while little difference was observed from that shown in table 4.13 only *both correct* responses were normally distributed. Pairwise comparisons showed that the perceived location of the target was significantly different from the actual position of the target for *both correct* reports ($t(7) = -3.87$, $p<0.02$) and where the colour adjacent to the target was reported (*letter correct/adjacent colour*: $t(7) = -6.56$, $p<0.02$).

Indeed, figure 4.13 clearly show that there was little difference in the distribution of the location responses for confident reports from those where all location responses were analysed.

Colour	Normalised Position	Confident	Unsure/Not Confident
Correct	TNN	87.09 (10.69)	12.79 (10.71)
Adjacent target	TNN	71.27 (20.21)	29.10 (21.92)
Non adjacent target	TNN	70.83 (40.05)	29.17 (40.05)
Colour shift: target	TNN	55.67 (45.26)	43.08 (46.16)
Colour shift: adjacent target	TNN	60.00 (56.57)	37.50 (53.03)
Colour shift: non adjacent target	TNN	0.00 (0.00)	100.00 (0.00)

Table 4.14: Mean (and standard deviation) confidence ratings expressed as a percentage for location in each target letter correct response category.

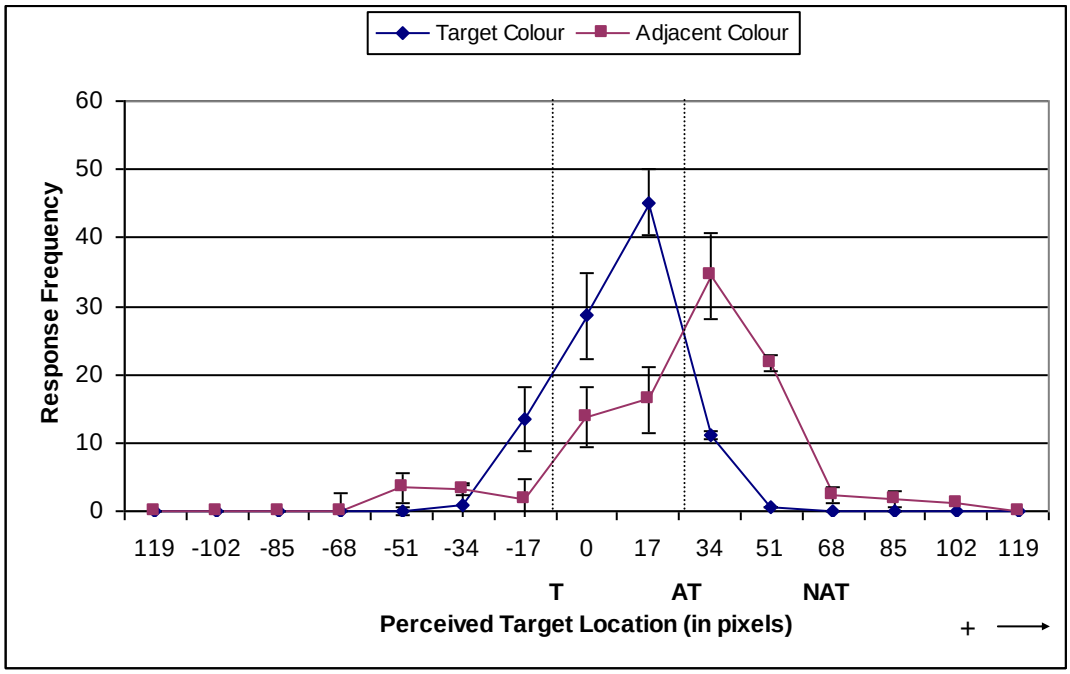


Figure 4.13: The percentage frequency for confident only both correct and letter correct/adjacent colour response categories. These are shown as the distance in pixels from the actual location of the target. T represents the centre of the target position (0 pixels) with the two non-targets shown at their respective locations (34 and 68 pixels). Error bars = +/- 1 standard error.

4.3.3.5 INDIVIDUAL OBJECT LOCATION

Did the distribution of responses for each individual reflect the distribution produced by averaging data across participants? As there were so few data points for some participants for all but both correct and adjacent illusory conjunction categories, investigating this question was only practicable for these reports. Nevertheless, these

response conditions still provided an indication of whether bias and the overall mean provided a good indicator for individual data. These are detailed in figures 4.14a to h. Overall, the bias in the perceived location of the target was found to be in the direction of fixation. For all eight participants, illusory conjunction reports indicated that it was the colour of the item adjacent to the target that provided the majority of the location information with the target shape providing the remainder. In sum, the overall pattern of results is not reflected in individual data with participants showing a wide variability in the uncertainty of their location responses. Nevertheless, individual data do support the earlier suggestion that it is a single feature that provides the location information for a complex object.

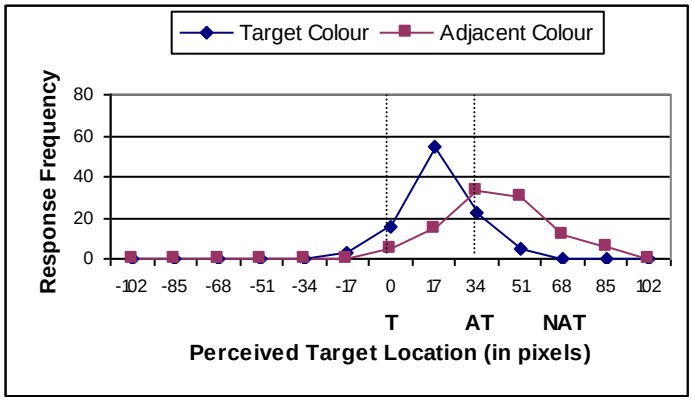


Figure 4.14a: Participant 1.

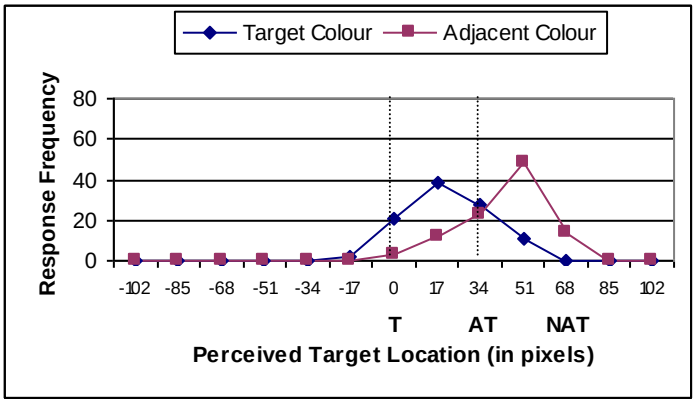


Figure 4.14b: Participant 2

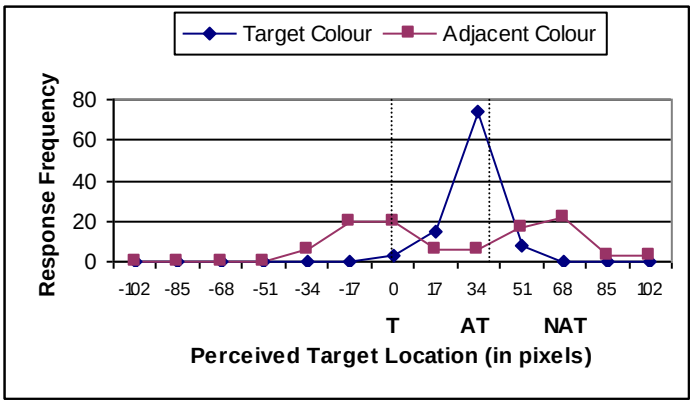


Figure 4.14c: Participant 3.

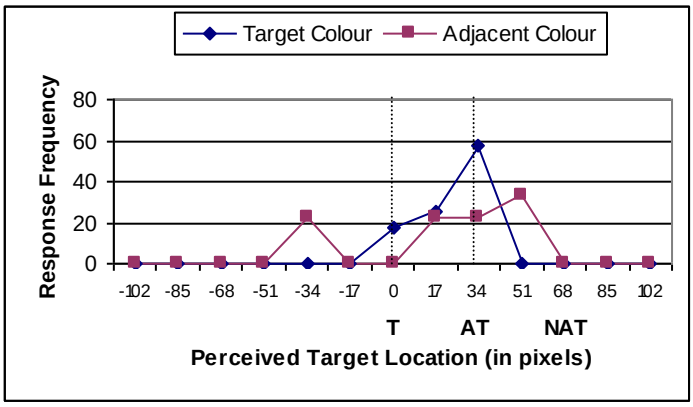


Figure 4.14d: Participant 4

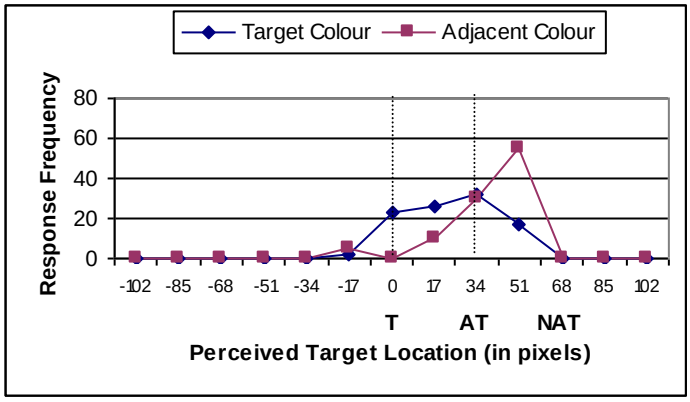


Figure 4.14e: Participant 5.

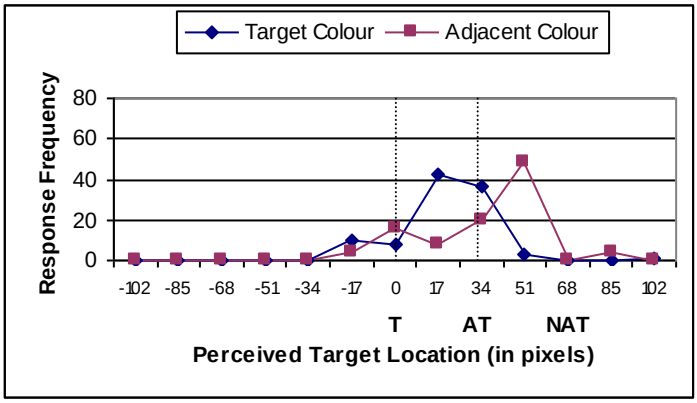


Figure 4.14f: Participant 6

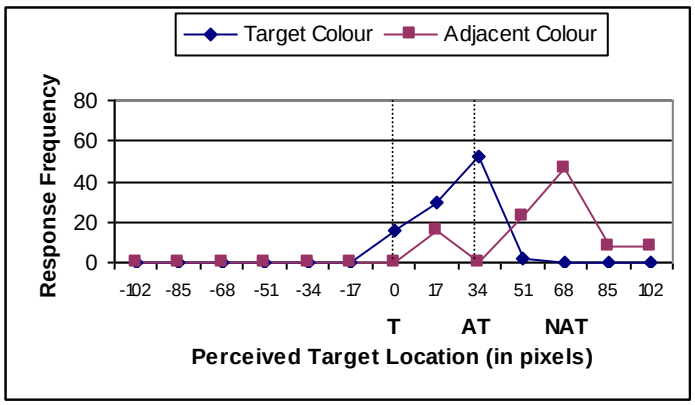


Figure 4.14g: Participant 7.

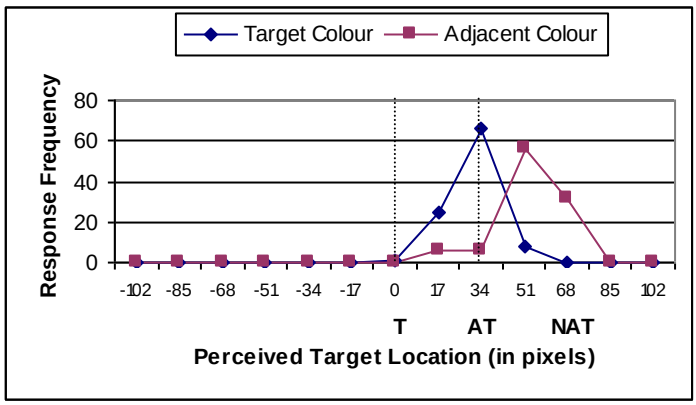


Figure 4.14h: Participant 8

4.3.4 DISCUSSION

No *incorrect colour* responses were again recorded regardless of whether the target letter was correct or not. This can probably be attributed to the identification and inclusion of tritan-like colour responses which have previously been classed as incorrect. This response category showed colour shifts that were consistent with those found in experiment nine and with Middleton & Holmes (1949).

However, while the frequency of incorrect target letter identification showed no appreciable difference between experiments nine and ten, on 63% of trials, both the shape and the colour were correctly identified in experiment ten, a significant increase from the 48% reported for experiment nine. It would seem reasonable to suppose that the increase in *both correct* responses was due to the reduced size of the stimulus array. This change also resulted in a considerable decrease for the remaining types of illusory conjunction responses from 42% in experiment nine to 20%, although a small increase in the number of tritan-like colour shifts from 3% to 5% was also noted. Despite the decrease in the number of illusory conjunction responses, an adjacency effect was again found, indicating that separate processing of feature detection and feature binding is taking place (e.g. Cohen & Ivry, 1989; Cohen & Shoup, 2000, Hazeltine *et* al, 1997; Keele *et al*, 1988; Prinzmetal & Mills-Wright, 1984; Rapp, 1992, Seidenberg, 1987). This was despite the fact that for every trial, spatial crowding occurred and thus violation of Bouma's bound (Andriessen & Bouma, 1976; Bouma, 1970; Chung *et al*, 2001; Pelli *et al*, 2004; Toet & Levi, 1992; Wilkinson *et al*, 1997).

Evaluation of both identification responses and attendant location data provided some evidence to suggest participants were still seeing either red as orange or green as lime when only unitary colours were present in the stimulus array. This would indicate

that when using colour, care should be taken not to include both red and orange or green and lime in the same colour strings.

The distribution of target correct responses was consistent with that found for experiment nine (one and a half target widths) and analysis of these showed that only 27% were correctly perceived to be located over the target area. This again suggests that while features can be correctly bound when attention is widely distributed (Cohen, 1997), only coarse (directional) location information is available (e.g. Prinzmetal *et al*, 1998; Treisman, 1993; Tsal & Baraket, 2005; Tsal & Meiran, 1993). There was also an indication of a systematic bias towards the fovea (Kerzel, 2002a, van der Heijden, van der Geest, de Leeuw, Krikke & Musseler, 1999) although this varied quite widely between participants. No evidence could be found for the computation of the centre-of-gravity which encompasses all featural elements before they are bound (e.g. Alvarez & Oliva, 2008; Chong & Treisman, 2003; Kowler & Blaser, 1995; Morgan *et al*, 1990).

Response categories also indicated that the location information might be sourced from either the shape or the colour of the bound object as suggested by the *unitary* rule of Snyder (1972) and Tsal & Lavie (1988). This is particularly evident for the perceived location where the non-target colour was chosen (figure 4.11) although great caution needs to be used as there were so little data.

4.4 EXPERIMENT 11

4.4.1 INTRODUCTION

The location results from experiment nine suggested that some stimulus colours were being incorrectly categorised indicating that participants were confusing red and orange or green and lime. Experiment ten confirmed this and showed that participants did appear to be seeing either red as orange or green as lime when only unitary colours were present in the stimulus array. To allow for this and to ensure that responses are correctly categorised, experiment eleven used colour strings comprised of five items that do not include either red and orange or green and lime. However, while this resulted in the use of some colours that fall along tritan lines, these were carefully chosen to ensure that any tritan-like colour responses could not be confused with any of the stimulus colours. This should still result in location responses being accurately attributed to the item perceived.

4.4.2 METHOD

4.4.2.1 DESIGN

As the purpose of these experiments was to determine the featural contribution to a bound object's perceived location, it was important to obtain as many illusory conjunction responses as possible. Therefore, in an attempt to increase their incidence, experiment eleven again used stimulus strings comprised of five items. This experiment is therefore identical to experiment nine in all respects except that the colours used in the stimulus display never placed red and orange or green and lime in the same stimulus string. As stimulus strings were comprised of five items, this resulted in the use of some colours that did not fall along tritan lines. Colour strings were carefully chosen to ensure that no stimulus colour was used within a string, that when perceived in a tritan-like manner, could match the colour from another item in the same stimulus string. No changes were made to the participants, apparatus, materials used or to the experimental procedure.

4.4.2.2 STIMULI

Colour	CIE χ co-ordinate	CIE γ co-ordinate	Luminance (cd/m^2)
Red	0.61	0.35	4.27
Green	0.31	0.58	14.68
Yellow	0.45	0.50	18.68
Blue	0.26	0.21	7.96
Orange	0.54	0.42	7.36
Purple	0.32	0.19	1.54
Lime	0.41	0.46	14.51
Pink	0.36	0.29	10.08
Grey	0.34	0.34	4.60

Table 4.15: CIE (1931) chromacity co-ordinates plus luminance for each stimulus colour used.

The target letters remained the same (T or X) and the two non-target letters were again randomly chosen from the following letters: OSGCU. The target letter was randomly assigned to either position one, two or three. There were six colour strings: purple, green, yellow, grey red; grey, red, green, purple yellow; lime, blue, red, grey yellow; purple, yellow, green, orange, red; grey, red, blue, lime, yellow; purple green red, grey, yellow. The CIE (1931) chromacity coordinates can be found in table 4.15. As before, the target letter (T or X) was known prior to the commencement of the

experiment but not the target colour. The size and positioning of the stimuli in the visual field remained identical to experiment nine.

4.4.3 RESULTS

4.4.3.1 OBJECT IDENTIFICATION

Six colour response types were identified and the overall mean percentage are detailed in table 4.16. Responses recorded as *letter incorrect* represented only 2% of the total trials. As for experiments nine and ten, no *letter correct/colour incorrect* responses were made at all. On 79% of trials, both the target letter and target colour were correctly identified (*letter correct/colour correct*). Responses categorised as illusory conjunctions fell into three categories: those colours from the items adjacent to either the left or the right of the target (*letter correct/distractor colour*); those colours that occupied the item in position three and were adjacent to the distractor (*letter correct/colour adjacent distractor*) or occupying position five in the stimulus string (*letter correct/non-target colour*). The three illusory conjunction categories totalled 13% of all trials (8%, 2% and 3% respectively). Contrary to expectations, participants were no more likely to report the colour of an item that was adjacent to the target than to report the colour of an item that was not ($t(7) = 1.44$; $p>0.05$). However, it should be noted that this result was solely due to one participant's responses. When removed, the remaining data showed a highly significant adjacency effect ($t(7) = 7.92$; $p<0.05$).

Colour		**Target Letter**	
		Correct	**Incorrect**
Correct	NTNNN	78.52 (6.08)	1.15 (0.88)
Distractor	NTNNN	7.94 (3.06)	0.17 (0.32)
Adjacent Distractor	NTNNN	2.06 (1.33)	none
Non-Target	NTNNN	2.58 (3.54)	0.24 (0.31)
Shift: Target	NTNNN	5.51 (3.26)	0.09 (0.16)
Shift: Distractor	NTNNN	0.80 (0.90)	0.04 (0.12)
Shift: Adjacent Distractor	NTNNN	0.35 (0.98)	none
Shift: Non-target	NTNNN	0.13 (0.18)	none

Table 4.16: Mean percentage mean (and standard deviation) of recorded identification responses.

Responses recorded as colour shifts represented only 7% of trials. Responses where the target colour was reported to shift (*letter correct/target colour shift)* represented 6% of trials but responses represented only 1% of trials where the colour of the item was adjacent to the target (*letter correct/distractor colour*). Where the colour

of an item not adjacent to the target (*letter correct/colour adjacent distractor* and *letter correct/non-target colour*) was perceived to shift, responses represented less than 1% (0.5%) when combined. However, as only *both correct* responses provided sufficient data for confidence analysis, therefore a great deal of caution is needed. Further, as reports expressing anything other than 'very confident' response decisions represented less than 1% of the total trials, confidence will not be analysed further except to say that this, together with no incorrect colour responses being recorded, suggests it is unlikely that illusory conjunction responses could be attributed to guessing and can therefore be seen as genuine perceptual phenomena.

4.4.3.2. OBJECT LOCATION

Raw scores were recorded as the pixel dispersal from the centre of the target (0 pixels). Contrary to that found for experiments eight and ten, the direction of fixation did not appear to overly influence location responses. Rather, it was adjacent items in the stimulus string that showed an influence as suggested by Kerzel (2002a). Data were then normalised by subtracting the perceived location from the actual target location to give a ± result in pixels with negative values represent location reports that moved away from the target in the opposite direction to fixation and positive values represent those response locations that moved from the target towards fixation. Table 4.17 shows the overall mean perceived location for each of the six possible response categories.

Colour	**Normalised Position**	**Target Letter**	
		Correct	**Incorrect**
Correct	NTNNN	-3.53 (4.15)	32.11 (12.59)
Distractor	NTNNN	37.69 (4.34)	39.28 (10.10)
Adjacent Distractor	NTNNN	52.99 (6.85)	none
Non-Target	NTNNN	93.72 (18.08)	128.50 (4.17)
Shift: Target	NTNNN	14.72 (17.71)	41.00 (32.53)
Shift: Distractor	NTNNN	48.20 (18.16)	27.00 (0.00)
Shift: Adjacent Distractor	NTNNN	56.88 (0.00)	none
Shift: Non-target	NTNNN	14.00 (89.10)	95.00 (0.00)

Table 4.17: The percentage mean (and standard deviation) of perceived location for each response category. The distance is a measure from the centre of the target (0 pixels).

A series of planned comparisons with Bonferroni correction (decreasing the critical p value to 0.0125), were conducted after data were tested for normality using

the Kolmogorov-Smirnov test. Only *both correct*, *letter correct/distractor colour*, *letter correct/adjacent distractor colour*, *letter correct/non-target colour* and *letter correct/colour shift target* were analysed due to a lack of data. All five tested response categories were shown to be normally distributed.

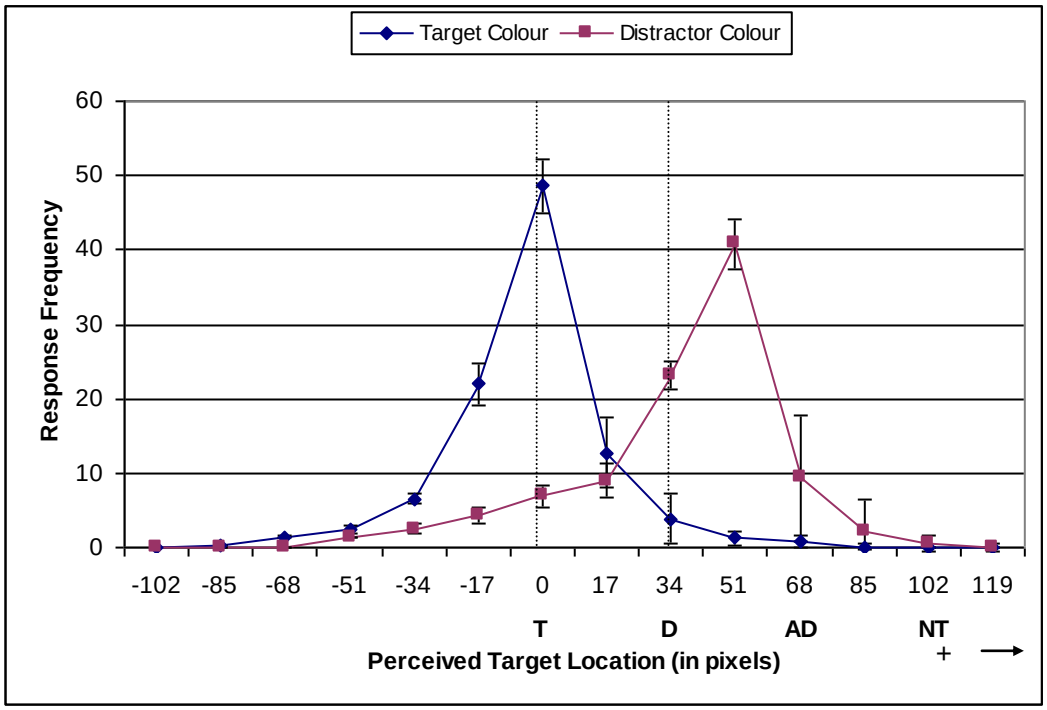


Figure 4.15: The percentage frequency for both correct and letter correct/distractor colour categories. These are shown as the distance in pixels from the actual location of the target. T represents the centre of the target position (0 pixels) with the adjacent items shown at 34 pixels. Error bars = +/- 1 standard error.

The mean overall location of both letter and colour correct responses (*both correct*) was shown to be within the area encompassed by the actual target position (17 pixels). This was confirmed by a pairwise comparison showing that there was no significant difference between *both correct* responses and the actual target position ($t(7) = -2.41$, $p > 0.01$). When a tritan-like colour shift was reported for the target colour (*letter correct/colour shift target*), the overall mean perceived location showed a slight shift from the edge of the target area (6 pixels) towards fixation and the pairwise comparison for the *target colour shift* category showed that the perceived location was indeed significantly different from the actual target position ($t(7) = 2.35$, $p < 0.01$).

The data for the item directly positioned to the left of the target in the stimulus display was normalised and amalgamated with the item directly to the right of the target. Thus, illusory conjunction reports for those items immediately adjacent to the

target showed that the mean perceived location was 30 pixels from the edge of the target area and the pairwise comparison confirmed that the perceived location of immediately adjacent illusory conjunctions was significantly removed from the actual target location ($t(7) = 24.58$, $p<0.01$). This indicated that it was colour that provided the location information. Examination of figure 4.15 indicated that when the target was correctly identified, the perceived location was centred round the target. When a colour from an item adjacent to the target was reported, (*letter correct/distractor colour*), location responses showed a distribution that mainly centred over the adjacent colour. However, what appeared to be a directional bias of one target width from this location is misleading and resulted from the way the data were plotted in that the normally distributed mean perceived location was 30 pixels from the edge of the target which is directly over the area encompassed by the distractor.

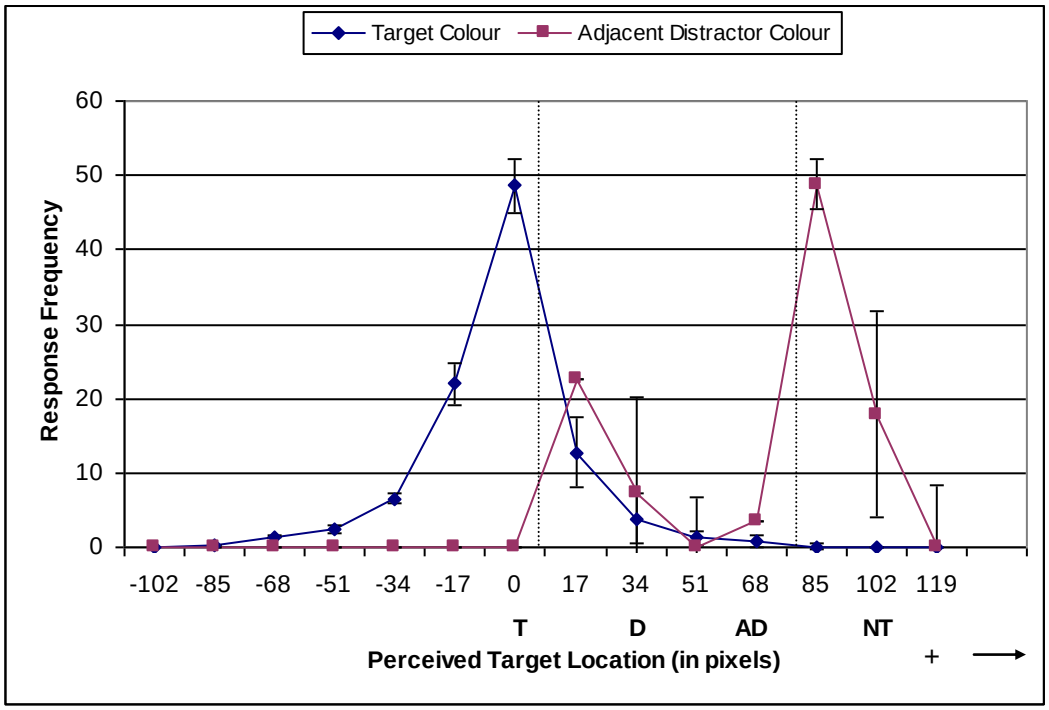


Figure 4.16: The percentage frequency for both correct and letter correct/adjacent distractor colour categories. These are shown as the distance in pixels from the actual location of the target. T represents the centre of the target position (0 pixels) with the two non-targets shown at their respective locations (34 and 68 pixels). Error bars = +/- 1 standard error.

A similar pattern was observed for illusory conjunctions comprised of a colour not adjacent to the target: *letter correct/adjacent distractor colour* and *letter correct/non-target colour*, both being confirmed by pairwise comparisons showing that in each case, the perceived location was significantly removed from the actual target

position ($t(7) = 21.87$, $p < 0.01$ and $t(7) = 13.71$, $p < 0.01$ respectively). When figure 4.16 was examined it showed that the perceived location of the item to the right of the distractor (*letter correct/adjacent distractor colour*) is sourced from the colour of that item with the target shape providing this information on only a small proportion of trials. However, where the illusory conjunction is formed from the non-target item (*letter correct/non-target colour*), the location information appears to be exclusively obtained from the item's colour (figure 4.17). In sum, there appears to be little indication that fixation exerts an influence although a consistent degree of location uncertainty is apparent. Further, there is an indication that it is a single feature that provides the location information.

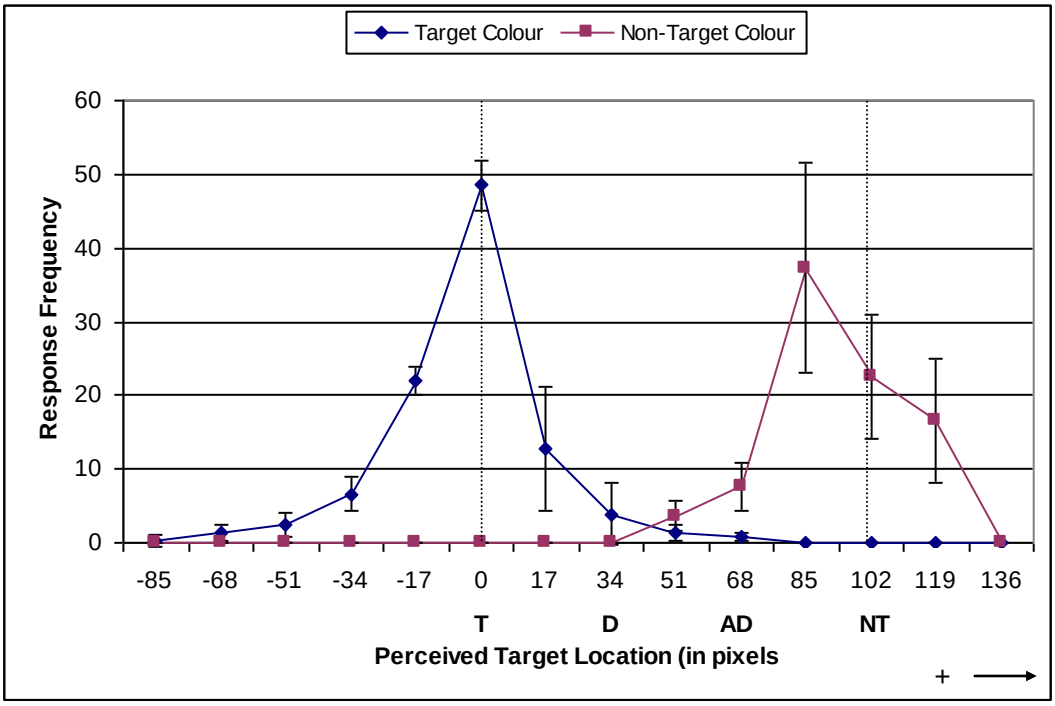


Figure 4.17: The percentage frequency for both correct and letter correct/non-target colour categories. These are shown as the distance in pixels from the actual location of the target. T represents the centre of the target position (0 pixels) with the two non-targets shown at their respective locations (34 and 102 pixels). Error bars = +/- 1 standard error.

Examination of target colour shift responses in figure 4.18, indicates that when a colour is perceived in a tritan-like manner, the perceived location becomes far more uncertain. This is contrary to that found in experiment eight but comparable to the results from experiment ten.

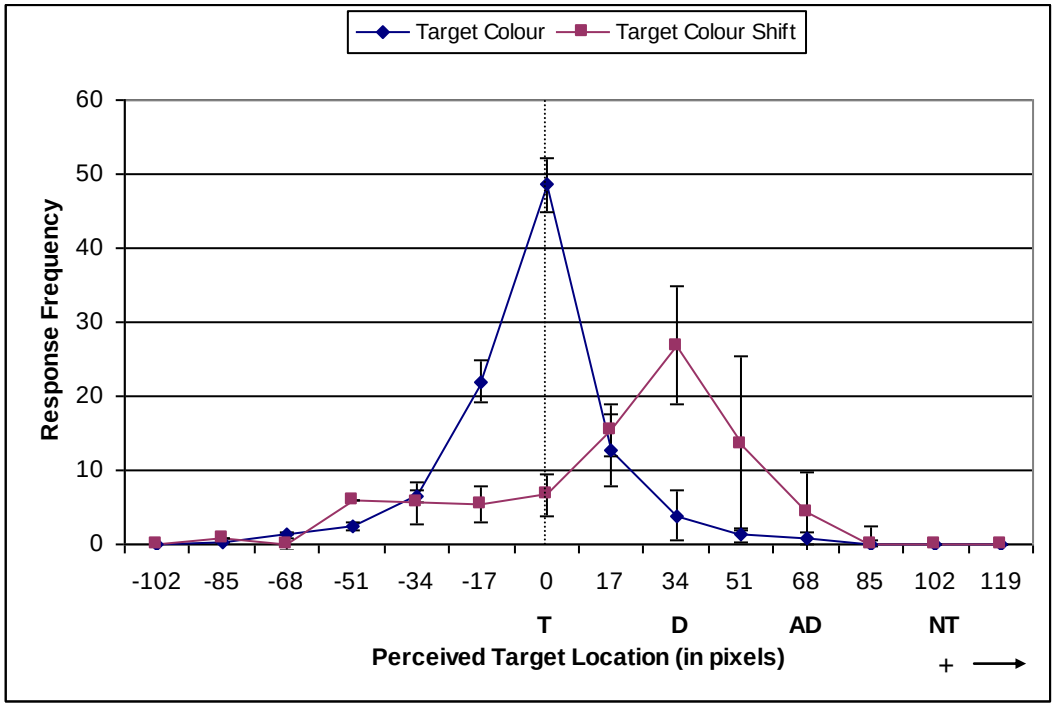


Figure 4.18: The percentage frequency for both letter and colour correct and letter correct/target colour shift response categories. These are shown as the distance in pixels from the actual location of the target. T represents the centre of the target position (0 pixels). Error bars = +/- 1 standard error.

INDIVIDUAL OBJECT LOCATION

Again, there were so few data points for some participants for all but both correct and adjacent illusory conjunction categories, only these are detailed in figures 4.19a to h. The distribution of responses for each individual, rather than reflecting the overall mean of 30 pixels from the edge of the actual target position, shows a bias of half a target width in the direction of fixation for seven of the eight participants. However, again, this is likely to result from the way the data were plotted for each individual participant the mean perceived location was within the area encompassed by the distractor. This indicated that the perceived location of the illusory object was obtained from the colour of that item, although on a very small proportion of these trials, it was the target shape that provided this information.

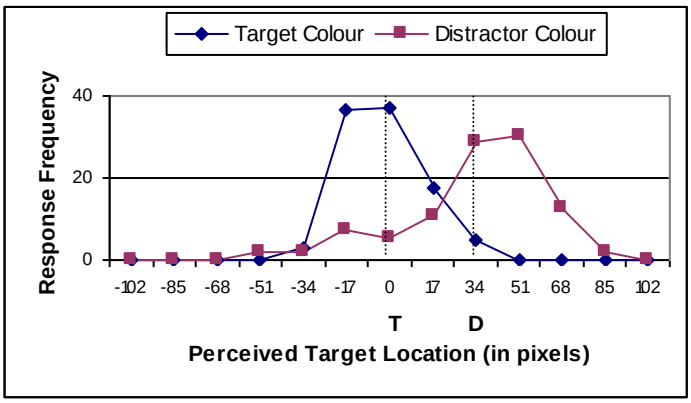


Figure 4.18a: Participant 1.

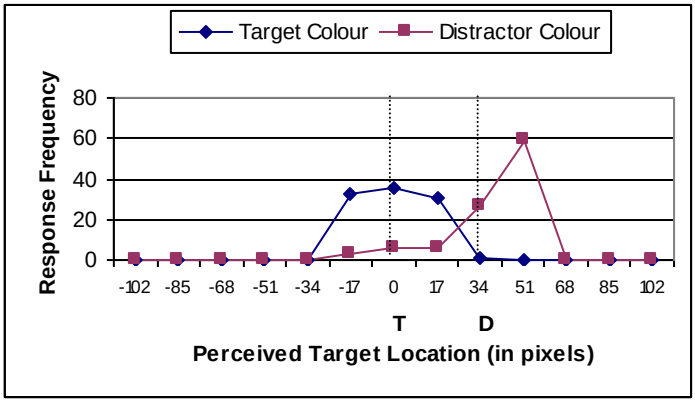


Figure 4.18b: Participant 2

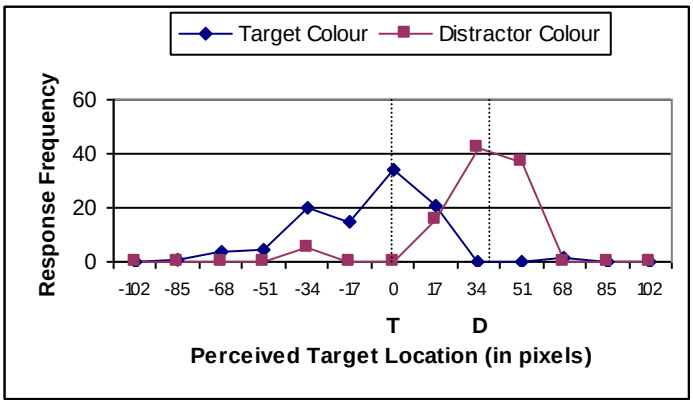


Figure 4.18c: Participant 3.

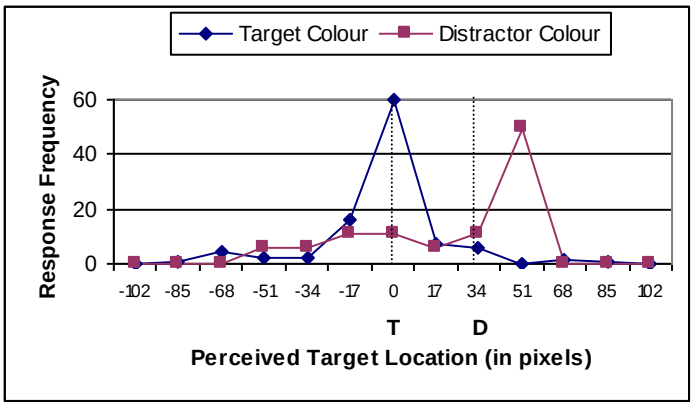


Figure 4.18d: Participant 4

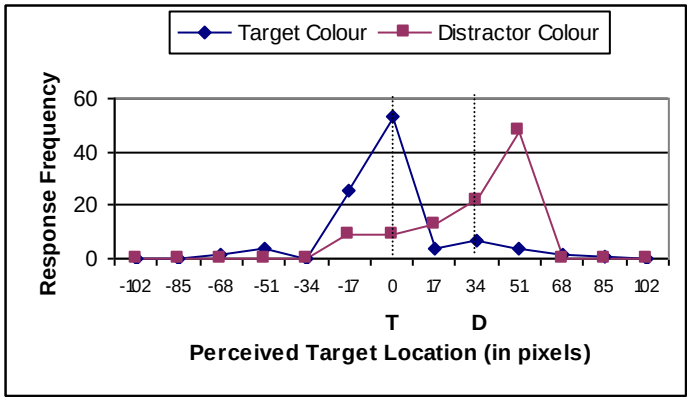


Figure 4.18e: Participant 5.

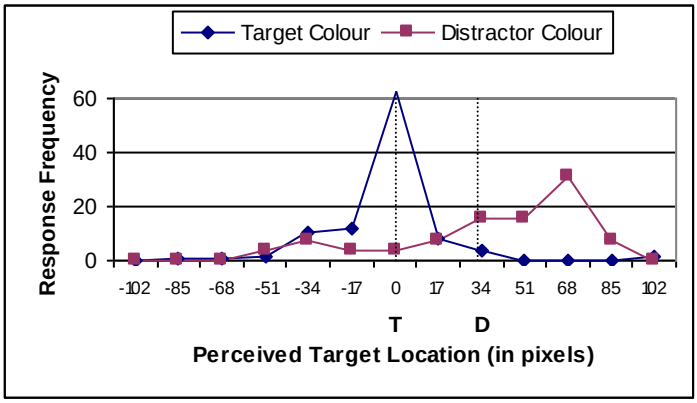


Figure 4.18f: Participant 6

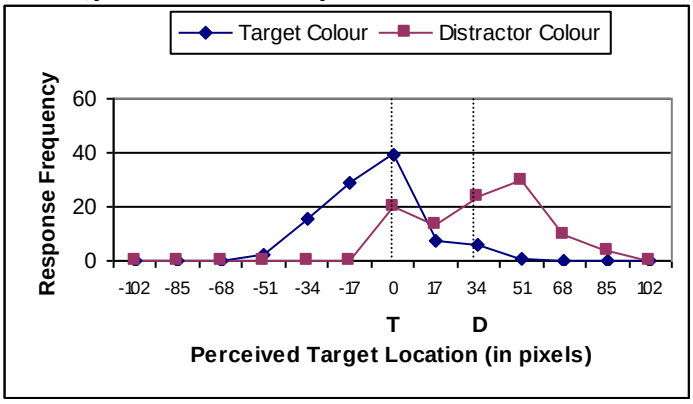


Figure 4.18g: Participant 7.

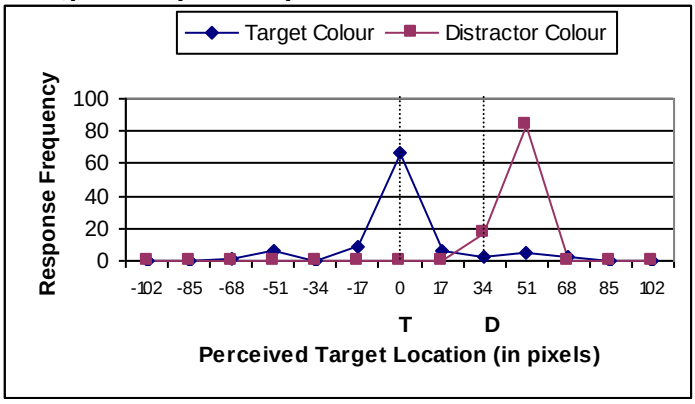


Figure 4.1h: Participant 8

4.4.3 DISCUSSION

No *incorrect colour* responses were again recorded. This was regardless of whether or not the target letter was correct and lends further support to colour errors being the result of tritan-like colour perception. Again, this response category showed colour shifts that were consistent with those found in experiment eight and with Middleton & Holmes (1949).

The frequency of incorrect target letter identification (3%) showed an appreciable difference from that found for experiments nine (7%) and ten (9%) which may be attributable to the combination of colours used in the stimulus strings. On 79% of trials, both the shape and the colour were correctly identified, this was a significant increase from the 48% reported for experiment nine and the 63% for experiment ten. Again, it would appear that the increase in *both correct* responses was due to the colours used in the stimulus arrays. This change also resulted in a considerable decrease for the remaining types of illusory conjunction responses from 42% in experiment nine and 20% in experiment ten, to 13% overall although a small increase in the number of tritan-like colour shifts (from 3% and 5% for experiments nine and ten respectively, to 7% in this experiment) was also observed. While there was an indication of an adjacency effect was present, that one participant reported no such effect, it is more likely that this finding is due to crowding.

The perceived location of target correct responses for this experiment indicated no systematic bias in the direction of fixation as suggested by Kerzel, 2002a and van der Heijden *et al*, 1999. Rather, the data showed a normal distribution round the actual location of the target. Further, analysis of this response category showed that 49% were correctly perceived to be located over the target area. This is a significant increase from that found for experiment nine (27%) and ten (28%) and suggests that for almost half of the trials, features can be correctly bound when attention is widely distributed (Cohen, 1997). Further investigation is needed to determine the accuracy found and the reasons why only coarse (directional) location information was available for the remaining trials (e.g. Prinzmetal *et al*, 1998; Treisman, 1993; Tsal & Baraket, 2005; Tsal & Meiran, 1993). No evidence could again be found for the computation of the centre-of-gravity which encompasses all featural elements before they are bound (e.g. Alvarez & Oliva, 2008; Chong & Treisman, 2003; Kowler & Blaser, 1995; Morgan *et al*, 1990).

There was further support found to indicate that location information may be sourced from either the shape or the colour of the bound object as suggested by the

unitary rule of Snyder (1972) and Tsal & Lavie (1988) although, as before, great caution needs to be used as there was so little data. Before rejection of either the *aggregate* model (Ashby *et al*, 1996; Hazeltine *et al*, 1997) or *random selection* model (Treisman, 1993, 2006; Treisman & Gelade, 1980), a considerable amount of data will need to be collected.

CHAPTER 5: GENERAL DISCUSSION AND FUTURE RESEARCH

5.1 GENERAL DISCUSSION

This thesis attempted to address the question of whether spatial information from individual features is asymmetrically integrated through competitive interaction via a *winner takes all* model (Treisman & Sato, 1990; Tsal & Baraket (2005) or is symmetrically integrated via an *aggregate* model (Hazeltine *et al*, 1997). By examining the contribution that location information from individual features makes to the perceived location of a bound object, the three rules relating to each of the integration models of interest could be tested. The *random* rule (Treisman & Sato, 1990) proposes that in distributed attention, features are randomly selected and an illusory conjunction can form which will be perceived to be located at any position within the attentional window. The *unitary* rule (Tsal & Lavie, 1988) suggests that it is the information from a single feature that can determine the perceived location of a bound object and the *spatial averaging* rule (Ashby *et al*, 1996) proposes that the information from all contributing features is averaged to provide the location information.

A straightforward way to determine featural contributions to the perceived location of complex objects is by using the illusory conjunction paradigm. Although usually used to determine whether correct feature integration requires focused attention, illusory conjunctions can also enable the identification of each contributing feature to perceived location, as each feature is obtained from items that are placed in different locations in the visual field.

Illusory conjunctions were first observed by Treisman & Gelade (1980). Treisman & Schmidt (1982) investigated them in more detail and concluded that the distance between objects had no effect on whether features from different objects in the visual field would be incorrectly combined to form an illusory conjunction. However, more recent studies have proposed that it is spatial proximity that will determine which features miscombine (e.g. Ashby *et al*, 1996; Chung *et al*, 2001; Cohen & Ivry, 1989, 1991; Cohen & Shoup, 2000, Hazeltine *et al*, 1997; Keele *et al*, 1988; Prinzmetal &

Mills-Wright, 1984; Rapp, 1992). For example, Cohen & Ivry (1991) proposed that the colour that appears closest to or within 1^{o} of the target letter is chosen. This results in an illusory percept being formed when the distractor colour is perceived to be closer to the target letter than the target colour due to the uncertainty about the actual location of a perceived feature. If there is independent location uncertainty about two features from different dimensions, then an illusory conjunction could form even when there is correct identification of the objects from which the features are derived (see also Chastain, 1982; Estes, 1975; Klein & Levi, 1987; Levi & Klein, 1989; Wolford & Shum, 1980). Therefore the illusory conjunction paradigm was used as a basis for each of the studies in this thesis.

However, in the studies described in this thesis, while an adjacency effect was found for the majority of experiments, none was found for experiments two, three and four. This would indicate that in peripheral vision perceptual errors result not just from an item that is immediately adjacent to the target (Cohen & Ivry, 1991) but may extend to any item in the stimulus array. When several objects are grouped around a target item, it has been demonstrated that the perception of the target is severely impaired by these objects if the distance between each item is equal to, or less than, half the distance between the target and a central fixation point (Bouma, 1970), a phenomenon known as 'spatial crowding'. Crowding is generally defined as a form of inhibitory interaction resulting from nearby contours. It has been shown to affect a broad range of stimuli and tasks such as the identification of orientation (e.g. Parkes *et al*, 2001), object size, hue and saturation (van den Berg, Roerdink & Cornelissen, 2007) as well as affecting visual search (e.g. Motter & Simoni, 2007). It has also been shown to occur for global features such as letters (Poder, 2006) and faces (Louie, Bressler & Whitney, 2007). Pelli *et al*, (2004) suggested that there is a close similarity between the conditions of crowding and those of illusory conjunctions, in that both predominate in peripheral vision or when objects are located near to the target. However, while it should be noted that Bouma's bound was violated in each of the multi-item experiments described above, the effects of crowding have been shown to be reduced when the target and non-target items differ in colour (Kooi *et al*, 1994) or when the target and non-target colours vary unpredictably,

thereby removing the top-down effect of *a priori* knowledge of the target colours (Poder, 2007).

Such findings would suggest that an immediate adjacency effect should have been apparent for these experiments. Although it was not possible to re-evaluate the data for experiments two, three and four, for the single participant in experiment eleven whose data showed no such adjacency, over 80% of the non-adjacent responses were comprised of a unitary colour (red, green, blue or yellow) rather than a binary colour (e.g. purple, orange, lime or turquoise). This would indicate that, at least for some participants, a unitary colour was more likely to be perceived than a binary colour regardless of its placement in the stimulus string. It is tempting to suggest that this lends support to Treisman and Gormican's (1988) proposal that before attention is narrowly focused, feature space is comprised of a set of unitary items such as red, blue, green and yellow. However, as non-unique adjacent binary colours were perceived even when a non-adjacent unitary colour were present, it may be that as Treisman (1993) suggested, feature space, rather than being discrete, is a continuum with more featural information becoming available as the distribution of attention narrows.

A further result of the present research was the observation made by many of the participants after completing experiments one and two that they had often perceived two intermediate binary colours (purple and turquoise). While it is possible that participants had perceived a non-target item coloured purple, turquoise was not used as part of any colour string so these colour misperceptions were investigated in experiments four to eight. For example, in experiment four, purple was used as a non-target colour on 60% of trials to determine whether purple was being perceived over unitary colours present in the stimulus display or whether purple was being perceived when it was not actually present in the stimulus string. Again, turquoise did not form part of any stimulus combination.

For the majority of trials where purple was reported as the target colour, it did indeed form part of the stimulus array. However, in these trials, both the target and the distractor colour were comprised of a unique unitary colour not present anywhere else in the set. As considerable evidence has been found to suggest that under these conditions, purple should not have been reported, it was difficult to account for why it would have

been perceived (e.g. Duncan & Humphreys. 1989; Reijnen *et al*, 2007; Treisman & Gormican, 1988) other than to again support Treisman's (1993) suggestion that feature space is a continuum where the amount of featural information increases as the distribution of attention narrows. However, on a small proportion of trials, purple was reported as the target colour when purple did not form part of the stimulus array. Similarly, the reported perception of turquoise could not be attributed to a non-target colour as it did not form part of any colour string used.

One possibility is that the perception of purple and turquoise on those trials where neither colour formed part of the stimulus string might have resulted from a statistical computation of either the average or ratio of grouped colours in the stimulus array (see Treisman, 2006; Ariely, 2001). There is some precedent for the statistical averaging of primitive features. For example, Ariely (2001), using sets of heterogeneous circles, found that participants could more easily recognise the mean size of the complete set than any one circle in the set. This effect was found regardless of the number of items in the display (see also Ariely & Burbeck, 1995). Chong and Treisman (2003) examined statistical averaging and attentional resources. They found that not only were participants as accurate when attention was distributed across twelve items as they were when there was only two but that accuracy was unaffected by either brief exposure durations (50 ms) or memory delays of up to 2 sec. Chong & Treisman (2004) proposed that when attention is distributed across the visual field, statistical processing automatically takes place. Chong & Treisman (2004) tested whether an illusory conjunction would be perceived when the target matched the mean size of the display. Displays consisted of twelve circles: three each of two fixed sizes used throughout, three of either an extremely large or small item to vary the mean size of the display and three that were either the target size (target present) or another distractor size (target absent). This resulted in four conditions: target present where the target matched the mean set size, target present where the target matched one of the fixed sizes and two identical conditions when the target was absent. On target absent trials, participants were significantly more likely to report the presence of a target that matched the mean size of the stimulus group, suggesting that an illusory conjunction can be perceived that is comprised of the mean size of all items present in the display. Parkes *et al* (2001) demonstrated that a statistical

average for orientation can be made even when individual items in the display cannot be detected (see also Dakin, 1997; Dakin & Watt, 1997; Heeley & Buchanan-Smith, 1990). Studies in motion perception have shown that even for displays containing items all moving in different direction, a reliable estimate of the average direction can be made (Williams & Sekuler, 1984). Such accuracy is evident even for displays of forty-five items when each item differs by as little as 1 to 2 degrees (Watamaniuk, Sekuler & Williams, 1989). Averaging has also been demonstrated for speed (De Bruyn & Orban, 1988; Snowden & Braddick, 1991; Watermaniuk & Duchon, 1992); luminance and roughness, (Oliva & Torralba, 2001). These studies indicate that averaging occurs very early in the processing cycle. Therefore, it is possible that the misperceived colours might have been due to some kind of averaging of colour information.

To determine if this was the case, statistical averaging was examined in experiments five and six. However, when statistical averaging was examined, which had been found for a number of features including luminance (Oliva & Torralba, 2001) and is consistent with the research on colour constancy (see Smithson, 2005 for a review), turquoise but not purple could be accounted for. This is consistent with Huang & Pashler's (2007) proposal that attention is a spatial pattern that itself provides data. Initially, visual input is distributed into feature maps. However, top down control only triggers the creation of a Boolean map which is a spatial representation that partitions a visual scene into two distinct regions: the region that is selected and the region that is not. When a Boolean map contains multiple items from a stimulus array, it describes only the global shape (outline). As all that is available is an accurate description of the entire region, a global description of multiple colours is not possible.

A second possibility is that the perceived colour of a single item was shifting in a tritan-like manner. Tritanopia is a low-level retinal effect resulting in the inability to perceive short wavelengths (blue) although there is also difficulty in perceived yellow. In 1903, König investigated tritanopes and found that they confused greenish-yellow with grey or rose-purple; blue-green with blue; yellowish-green with bluish violet; and orange with reddish purple. He also found that both yellow and blue were matched with grey.

However, even in normal vision, anatomical studies have shown that the centre of the foveola is tritanopic in that there are no shortwave mechanisms in a central area

where L and M cones reach maximum density with S cones reaching maximum density at 1^{o} eccentricity (Curcio, Sloan, Kalina & Hendrickson, 1990). Transient tritanopia, a low-level retinal effect resulting from a problem with adaptation (Stiles, 1949) was first observed by Willmer (1944). He found that people with normal vision sometimes perceived a target colour presented in the central fovea in a similar way to those who were blue-yellow colour blind. However, it has been suggested that transient tritanopia behaves somewhat differently to tritanopia. Middleton & Holmes (1949) measured induced tritanopia in observers with normal vision and found that in chromaticity space, rather than unique green (530) to unique red (700), matches reflected a line in chromacity space (see figure 4.2, p 149) that ran in the direction greenish-blue (487-490) to orange (595-625). Middleton & Mayo (1952) also found an increase in the number of blue to green responses to stimuli when the visual system moves from trichromatic to tritan-like behaviour. Indeed, Mollon (1982) suggests that tritanopia should never be equated with the absence of a blue sensation if an observer has access to normal trichromatic vision but should instead be regarded as resulting from stimulus parameters being viewed under tritanopic conditions (transient tritanopia). Under such conditions, visual perception will usually be dominated by blue. Two neutral points have also been observed. The first lies near 400 nm (violet). The second is in the spectral region of 570-580 nm (yellow) and occurs when either illumination is reduced (Middleton & Mayo, 1952), when the targets are displaced to the periphery (Gordon & Abramov, 1977), or when targets are briefly presented (Weitzman & Kinney, 1967). Therefore, it is possible that when participants were reporting seeing purple or turquoise, they were actually perceiving a tritanopic hue shift from orange to purple or green to turquoise.

While some initial evidence was found for this in experiment seven, to test whether tritan-like colour shifting was consistently and exclusively occurring, experiment eight used a parafoveally presented stimulus comprised of a single coloured letter. Every colour from experiments one to seven was tested. Results indicated that without exception, every reported colour shift matched those found by Middleton & Holmes (1947). Therefore, it was reasonable to suppose that when stimuli are presented both parafoveally and briefly, the perception of colour, whether unitary or binary, could result in a tritan-like shift in colour space. Thus for experiments one to four, on those trials

where purple had been reported as the target colour when it did not form part of the stimulus array, orange was present as a non-target colour. Both König (1903) and Middleton & Holmes (1947) found that orange could shift to a reddish purple. Similarly, the perception of turquoise could be attributed to a tritan-like shift of green while the perception of aquamarine, a darker turquoise, could be attributed to a tritan-like shift of blue. In sum, these results would indicate that the perception of an illusory conjunction is not confined to the target letter being bound with a non-target colour but can also result from the target shape being bound with a tritan-like shift of a stimulus colour.

However, in experiment nine, multi-item displays were used with colour strings comprised of combinations of red, green, yellow, orange and lime and it was found that several participants might be confusing red with orange and green with lime. Indeed, previous research into attentional effects using colour stimuli showed evidence of colour shifting for both unitary and binary colours that did not conform to the colour shifts observed for transient tritanopia (Prinzmetal *et al,* 1998). They found that rather than shifting towards blue as would be expected for a tritan-like perception, green appeared more lime. This could, however, be accounted for by gender differences as half of their participants were male. It has been observed that male perception of green is skewed towards lime while for females, it is not (e.g. Volbrecht *et al*, 1997). Indeed, in the above studies, there was a clear demonstration that it was male participants who tended to perceive green as lime on some trials. However, in Prinzmetal *et al's* (1998) study, other colours also moved along the colour spectrum rather than being perceived with blue added or subtracted. It should be noted however, that while only a single colour was used as a stimulus in their study, a colour wheel was always present during the trial (see figure 3.6; page 135) and a colour from this may have been perceived instead. The second finding that red was occasionally perceived as orange was not gender specific and mirrored more closely the responses of tritanopes.

One further issue regarding colour also became apparent relating to the problem of guessing and making estimations based on feature error rates. This appears to have been difficult to resolve for studies using the illusory conjunction paradigm (see pages 31-35). For example, it has been suggested that blinking, inattention or not fixating correctly may result in either the target letter or colour being guessed (e.g. Bonnel & Prinzmetal, 1998).

However, once tritan-like colour shifting had been identified, it became apparent that no colour responses were being recorded as colour errors. This occurred consistently across the latter experiments and it would therefore seem entirely reasonable to suggest that participants seldom, if ever, make guesses about a target's colour, even when they feel do not feel confident about some of the choices they made. To assume that those colour responses not recorded as either correct or as illusory conjunctions must be attributable to guessing and then to use them to determine whether illusory conjunctions are true feature binding errors, may be a misguided strategy.

In sum, the above findings indicate that research using colour within the illusory conjunction paradigm needs to take particular account of incidents of transient tritanopia in order to avoid response data being recorded incorrectly as a colour error or as an illusory conjunction. For instance, in a display comprised of five coloured letters: S G T O U, a colour response of turquoise would be considered an error or a guess when it is more likely to have been a tritanopically perceived green target. Further, for the display: S G T O U, where the target colour was orange but the participant's colour response was purple, it would not be certain whether an illusory conjunction had been perceived between the target letter (T) and the colour from the 5th item in the display or whether the target colour had been perceived tritanopically. Therefore, if tritan-like colour responses are not clearly identified, results may show a falsely elevated frequency of illusory conjunctions.

In what way did these different types of colour responses affect the perceived location of a bound object? One obvious problem was that in the early experiments, it was impossible to distinguish between the accurate perception of a colour from one item in the stimulus string and a tritan-like perception of a colour from a different item in the stimulus string. For example, on the majority of trials for experiments one to three, both orange and purple were present in the colour array. As orange can be perceived as reddish purple when a tritan-like shift occurs, participants may have reported the location of the orange item rather than the location of the purple item. Further, as participants were only given the three potential target colours (red, blue and yellow) as response options, they would had to have chosen either red or blue despite providing a location response that related to a non-target item. Where this colour response then indicated that

an illusory conjunction had been perceived from an adjacent item, it would result in the location report being attributed to an incorrect item in the array and would seriously affect the reliability of the location data. Therefore, it is not surprising that the early experiments had provided no clear indication as to whether the source of the location information was *random* (Treisman & Sato, 1990), *unitary* (Tsal & Lavie, 1988) or *spatially averaged* (Ashby *et al*, 1996; Hazeltine *et al*, 1997).

The findings from experiments eight, ten and eleven provided a clearer picture. Results indicated that no colour responses were recorded as incorrect in that they could not be accounted for as being either attributable to an item in the colour array or as a tritan-like colour response. This was the case even when the target shape was incorrectly identified. However, there was an initial concern that participants may have confused green with lime or red with orange due to reported location responses for a proportion of these colours. This was confirmed in experiment ten, albeit on a very small proportion of trials and not for all participants. It appears likely that when multicolour displays are used, some colours (red and orange or lime and green) are perceptually less distinguishable than would be expected despite the binary colours being comprised of equal amounts of red and yellow (orange) and green and yellow (lime). This places a further constraint on the colours that can be used in multi-colour displays particularly where perceived location is an issue. Indeed, when colour had been carefully controlled for, an increase from 27% of correctly identified targets that were perceived to be located over the actual target area (experiment nine) to 49% (experiment eleven) was observed.

Findings for these experiments also indicated that the overall mean perceived location for *target correct* response categories was normally distributed over the target area although for experiment ten, a bias of approximately half a target width in the direction of fixation was observed. However, while a degree of uncertainty was apparent for both experiments eight, ten and eleven, this amounted to a maximum of seven pixels from the edge of the target across all *target letter correct* responses and responses were normally distributed around either the target item or - in the case of illusory conjunctions - around the item that had provided the colour information for the majority of trials and around the target shape for the remainder. This was therefore not sufficient to suggest that a location bias was present. However, when a target colour had been perceived in a

tritan-like manner, location uncertainty increased considerably and little structure to the response distribution was evident. It is therefore difficult to reconcile these results with the research indicating that positional uncertainty is likely to be determined by either a foveal bias (Kerzel, 2002, van der Heijden, van der Geest, de Leeuw, Krikke & Musseler, 1999) or by other items present in the display (Werner & Diedrichsen, 2002).

Binding Rule		Prediction	Found
Aggregate Rule (Ashby et al, 1996)	The location information from each contributing feature is averaged to determine the perceived location of a bound object.	Over trials, a normal distribution will form centred over the midpoint between both contributing features.	No
Random Rule (Treisman & Sato, 1990)	No location information is available before the focus of attention is applied so that feature localisation is random.	Over trials, location data will form a rectangular distribution encompassing the whole visual field.	No
Unitary Rule (Tsal & Lavie, 1988)	Location information is obtained from a single feature that has contributed to the illusory object (either colour or shape).	Over trials, location data will form a binary distribution over both items.	Yes

Table 5.1: The three different location rules tested relating to the formation of illusory conjunctions together with attendant predictions.

Further, Treisman (2006) maintained that the perceived location of illusory bindings is random and occurs at any point within the attentional window but this was not borne out by the data from the experiments reported in this thesis. Indeed, no indication of such randomness was observed, even when analysis was restricted only to responses within the confines of the stimulus string. Rather, there was considerable structure found for the perceived location of illusory conjunctions: they appeared to be centred round the item from which the colour had been perceived. The overall mean perceived location of illusory conjunctions appears to be centred over the colour of the contributing item. This strongly indicates that the source of the location information is obtained from a single feature, as suggested by the *unitary* rule (Tsal & Lavie, 1988). It does not support the idea that features are *randomly* selected to form an illusory conjunction which will be perceived to be located at any position within the attentional window as proposed by the *random* rule (Treisman & Sato, 1990). Nor is it consistent with the proposal that it is the

information from both contributing features that is *averaged* to provide the location information as put forward by Ashby *et al* (1996).

For the present research where the perceived locations of illusory conjunctions were being examined, it was crucially important that true illusory conjunctions be correctly identified so that location responses could be accurately attributed to the perceived item. This was in order to determine whether it was the target shape, a non-target colour or both features that contributed to the location response of a perceived object or indeed whether location responses were randomly distributed across the width of the stimulus display.

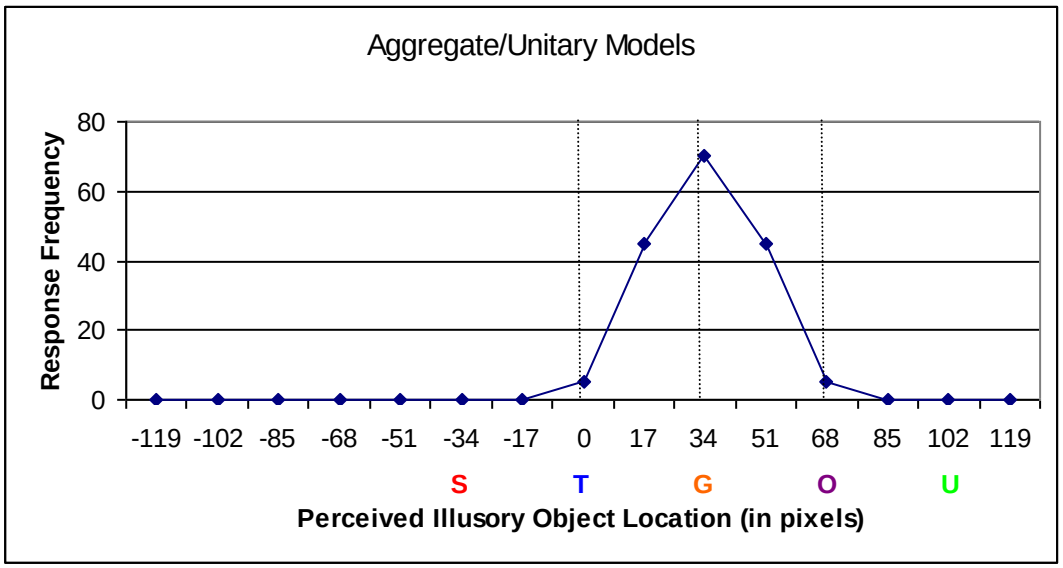


Figure 5.1a: graph showing the confusion in interpretation of the data when incorrectly identified illusory conjunctions are recorded. The perceived location would indicate that an amalgamation of both the target shape and non-target colour (purple) in position 4 had jointly provided the location information (aggregate model). In actuality, the non-target orange O in position 3 had been perceived tritanopically as purple, indicating that a single feature had provided the location information (unitary model).

If transient tritanopia was not accounted for and any tritan-like responses were incorrectly identified as illusory conjunctions, spurious location responses could result in the incorrect model being supported. For example, using the colour string S T G O U, with the T being the target, colour responses might be recorded as purple and the location as being centred over the G. If the purple response was incorrectly categorised as being an illusory conjunction+ between the target letter (T) and the colour (purple) from the 4th item in the display, rather than as a tritanopically perceived orange item in position 3, the

attending location response would suggest that it was an *aggregate* of both the target shape (T) and purple O rather than solely the colour from the 3rd item (orange) providing the location information as indicated by the *unitary* model (see figure 5.1a).

Further, if a similarly incorrect analysis encompassing all of the non-target items was made over numerous trials, then the distribution of location responses would erroneously imply that the *random model* was correct (see figure 5.1b).

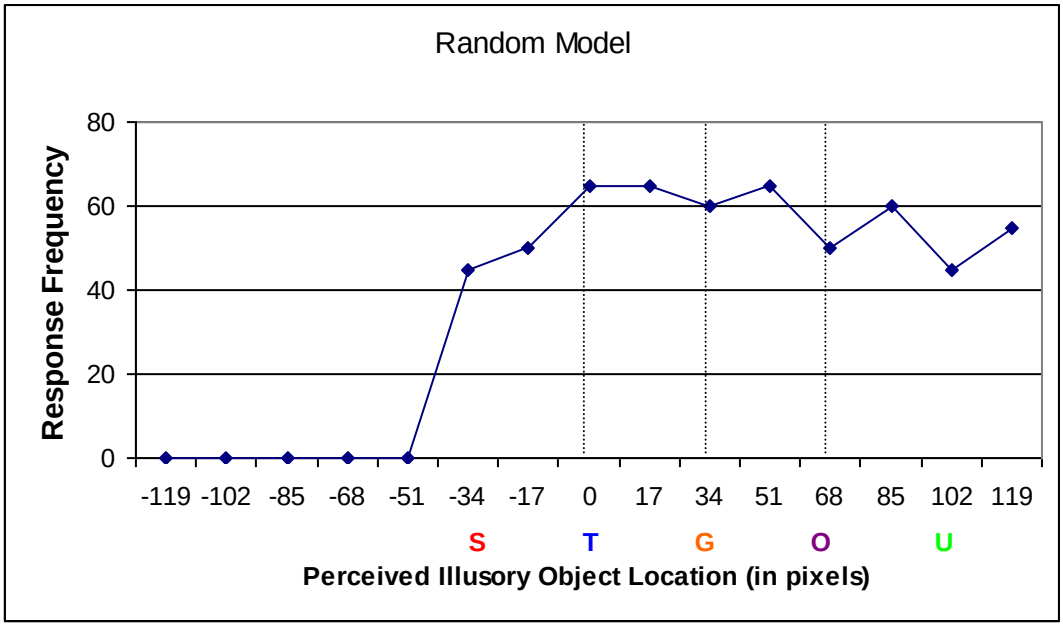


Figure 5.1b: graph showing an apparently random distribution of location responses when incorrectly illusory conjunctions are incorrectly recorded for all of the non-target items in the stimulus display.

It can be seen that once a careful account of tritanopia is taken, using only colours that do not lie on tritan confusion lines so that data are correctly categorised and illusory conjunctions accurately identified, responses from experiment eleven show a reasonable degree of structure with the mean perceived location being centred around the item contributing colour information to the illusory conjunction. Therefore, such responses are not *random* in the way suggested by Treisman and Schmidt (1982) in which location responses for illusory conjunctions are distributed across the visual field. Nor do they conform to the *aggregate model* in which it was suggested that an amalgamation of location information from both contributing features (colour and shape) provides the location information for a complex object (Ashby *et al* 1996; Hazeltine *et al*, 1997). Rather, the perceived location of an illusory object appears to be centred over a single

feature (colour). This seems to be modelled best by the *unitary* rule proposed by Tsal & Lavie (1988). Although their study did not use the illusory conjunction paradigm, they did state that it is a single object that provides the location information (albeit in their case, the target shape). Further studies would provide considerably more data, so that the featural contribution to the perceived location of complex objects could be more accurately identified.

In what way might these results relate to current theories of feature integration? The data do not support Treisman & Schmidt's (1982) proposal that individual features can be identified but not located so that individual features are free-floating in relation to each other when focused attention is prevented or diverted. They are also not consistent with Treisman's (2006) further assertion that the perceived location of an illusory percept will be randomly located anywhere within the attentional window. Rather, results showed that while only coarse location information is available when attention is widely distributed, the considerable structure found (in the sense that the perceived location of an illusory conjunction is normally distributed round the item that provided the colour information) indicates not only that individual features are bound to coarsely defined locations before the focus of attention is applied (e.g. Tsal & Baraket, 2005) but that it is information from a single feature that will provide the location information when a complex object is perceived (Tsal & Lavie, 1988). Therefore, it is unlikely that at the preattentive stage, the visual system is only capable of detecting the presence of individual features across the visual field, with localisation only being under attentional control as postulated by Treisman (2006). Results may be more indicative of Tsal & Baraket's (2005) proposal that binding occurs via one of several overlapping attentional receptive fields which are distributed across the visual field. These provide only minimal spatial resolution. An increase in attentional resources facilitates the computations needed to provide increasing localisation precision. Thus, while coarse spatial information is provided by the attentional receptive field that shows the greatest activation, fine spatial information is obtained by integrating the outputs of each attentional receptive field that has detected the object and computing their relative activation (see also Tsal & Lavie, 1988; Tsal, Meiran & Lamy, 1995; Tsal & Shalev, 1996).

5.2 FUTURE RESEARCH

In this thesis a number of methodological problems were noted and corrected. However, of serious concern throughout was the issue of whether data averaged across all participants were a good representation of individual data in respect of the perceived location of bound objects. While the early studies indicated that this was not the case, it became apparent that this may be due to the way the data were collected. Initially, no distinction was made between the positions in the visual field in which the stimulus arrays were presented in respect of fixation. When this was rectified in experiments eight to eleven, data averaged across all participants provided a good representation of individual data. Any future studies should therefore take careful note of any individual differences when generalising findings to the wider population. It became apparent in experiment eleven that too many constraints were being put on the design of the stimulus arrays in order to resolve all of the issues resulting from the previous experiments. This led to very few illusory conjunction responses being recorded. Consequently, the main purpose of this thesis which was to determine the source of location information when an illusory conjunction is perceived was not being adequately addressed. Further research will need to be conducted that restricts manipulations in such a way as to resolve these issues.

Similarly, while the use of the same participants throughout the course of the thesis ensured that good quality data was collected, over time, they each became so proficient that accuracy levels increased and fewer illusory objects were recorded. To ensure sufficient data is obtained, either the experiment will need to be repeated several times with the same participants or new participants would need to be found.

A further issue related to participants' ages. By the end of the thesis, the oldest participant was 54. It has been shown that in preattentive processing, older adults exhibit difficulty in localising objects. For example, Owsley, Burton-Danner & Jackson (2000) found that adults aged 61 upwards exhibit problems with spatial localisation during feature search of up to three target widths regardless of set size. However, when the data were re-examined in experiment eight for single item displays, only the 54 year old showed an error magnitude of four target widths. However, in experiment eleven which

used multi-item displays, all participants over 40 years (4) were shown to be just as accurate in their localisation responses as their younger counterparts. Therefore, this finding warrants further investigation.

This thesis has not only demonstrated that experimental design is of the utmost importance in investigating the ways in which features are bound into the complex objects we easily recognise but that a detailed qualitative analysis of participants' responses can identify strategies that would not otherwise be apparent.

5.3 TRANSIENT TRITANOPIA and FUTURE RESEARCH

In this thesis a number of methodological problems were noted and corrected. However, of serious concern are the constraints transient tritanopia imposes on experiments using the illusory conjunction paradigm. In particular, experiments that measure the binding of colour with a second feature may provide incorrect data when the colours used lie on tritan confusion lines (see figure 4.4; p 154). Therefore, to ensure that true illusory conjunctions can be correctly identified and measured, any such research should carefully control any colours used to ensure that they do not lie on tritan confusion lines.

5.4 OTHER ISSUES FOR FUTURE RESEARCH

Of serious concern throughout the thesis was also the issue of whether data averaged across all participants were a good representation of individual data in respect of the perceived location of bound objects. While the early studies indicated that this was not the case, it became apparent that this may be due to the way the data were collected. Initially, no distinction was made between the positions in the visual field in which the stimulus arrays were presented in respect of fixation. When this was rectified in experiments eight to eleven, data averaged across all participants provided a good representation of individual data. Any future studies should therefore take careful note of any individual differences when generalising findings to the wider population. It became apparent in experiment eleven that too many constraints were being put on the design of the stimulus arrays in order to resolve all of the issues resulting from the previous experiments. This led to very few illusory conjunction responses being recorded. Consequently, the main purpose of this thesis which was to determine the

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This thesis has not only demonstrated that experimental design is of the utmost importance in investigating the ways in which features are bound into the complex objects we easily recognise but that a detailed qualitative analysis of participants' responses can identify strategies that would not otherwise be apparent.

REFERENCES

Adam, J. J., Ketelaars, M. & Hoek , T. (1993). On the time course and accuracy of spatial localizations: Basic data and a two-process model. *Acta Psychologica, 84,* 135-159.

Alvarez, G. A, & Oliva, A. (2008). The Representation of Simple Ensemble Visual Features Outside the Focus of Attention. *Psychological Science, 19(4),* 392-398.

Andersen, R. A. (1987). Inferior parietal lobule function in spatial perception and visuomotor integration. In: F. Plum & V. B. Mountcastle (Eds.). (1987). *Handbook of physiology,* section 1: *The nervous system,* volume 5: *Higher functions of the brain,* pp 483-518. Bethesda, Md: American Psychological Society.

Andersen, R. A., Asanuma, C., Essick, G. & Siegel, R. M. (1990). Corticocortical connections of anatomically and physiologically defined subdivisions within the inferior parietal lobule. *Journal of Comparative Neurology, 296,* 65-113.

Andersen, G. J. & Kramer, A. F. (1993). Limits of focused attention in three-dimensional space. *Perception & Psychophysics, 53(6),* 658-667.

Andriessen, J. J. & Bouma, H. (1976). Eccentric vision – adverse interactions between line segments. *Vision Research, 16 (1),* 71-78.

Appleman, I. B. & Mayzner, M. S. (1982). Application of geometric-models to letter recognition – distance and density. *Journal of Experimental Psychology: General, 111(1),* 60-100.

Arguin, M., Cavanagh, P. & Joanette, Y. (1994). Visual feature integration with an attentional deficit. *Brain & Cognition, 24,* 44-56.

Ariely, D. (2001). Seeing Sets: Representation by Statistical Properties. *Psychological Science, 12(2),* 157-162.

Ariely, D. & Burbeck, C. A. (1995). Statistical encoding of multiple stimuli – A theory of distributed representation. *Investigative Ophthalmology & Visual Science, 36(4),* S472.

Arnold, D. H., Clifford, C. W. G. & Wenderoth, P. (2001). Colour is processed faster than motion. *Australian Journal of Psychology, 53(supp. S),* 42-42.

Ashby, F. G., Prinzmetal, W., Ivry, R. & Maddox, W. T. (1996). A formal theory of feature binding in object perception. *Psychological Review, 103 (1),* 165-192.

Atkinson, J. & Braddick, O. J. (1989). Where and what in visual search. *Perception, 18(2),* 181-189.

Atkinson, R. C., Holmgren, J. E. & Juola, J. F. (1969). Processing time as influenced by number of elements in a visual display. *Perception &, Psychophysics, 6(6a),* 321.

Attneave, F. (1974) How do you know. *American Psychologist, 29 (7),* 493-499.

Baizer, J. S., Ungerleider, L. G. & Desimone, R. (1991). Organization of visual inputs to the inferior temporal and posterior parietal cortex in macaques. *The Journal of Neuroscience, 11,* 168-190.

Baldassi, S. & Burr, D. C. (2000). Feature-based integration of orientation signals in visual search. *Vision Research, 40,* 1293-1300.

Bálint, R. (1909). Seelenlähmung des "Schäuens", Optische Ataxia, Raumliche Storung Aufmerksamkeit *Montatsschrift fur Psychiatrie und Neurologie, 25,* 51-81. Translated by Harvey, M. (1995). *Cognitive Europsychology, 12,* 265-281.

Ballard, D. H. (1986). Cortical connections and parallel processing: Structure and function. *Behavioural & Brain Sciences, 9,* 67-120.

Baron, J. (1973). Perceptual dependence – evidence for an internal threshold. P*erception & Psychophysics, 13 (3),* 527-533.

Batchelder, W. H. & Reifer, D. M. (1990). Multinomial processing model of source monitoring. *Psychological Review, 97,* 548-564.

Bauer, B., Jolicoeur, P. & Cowan, W. B. (1996). Visual Search for Colour Targets that Are or Are Not Linearly Separable from Distractors. *Vision Research, 36(10),* 1439-1465.

Baylis, G. C. & Driver, J. (1992). Visual parsing and response competition: The effect of grouping factors. *Perception & Psychophysics, 51(2),* 145-162.

Baylis, G. C. & Driver, J. (1993). Visual attention and objects, Evidence for hierarchical coding of location. *Journal of Experimental Psychology, Human Perception &, Performance, 19,* 451-470.

Beck, J. (1966). Perceptual grouping produced by changed in orientation and shape. *Science, 154,* 538-540.

Beck. J. (1967). Perceptual grouping produced by line figures. *Perception &. Psychophysics, 2,* 491–495.

Bedell, H. E., Chung, S. T. L., Ogmen, H. & Patel, S. S. (2003). Color and motion: which is the tortoise and which is the hare? *Vision Research, 43(23),* 2403-2412.

Beiderman, I. (1972). Perceiving real-world scenes. *Science, 177,* 77-80.

van den Berg, R, Roerdink, J. B. & Cornelissen, F. W. (2007). On the generality of crowding: visual crowding in size, saturation, and hue compared to orientation. *Journal of Vision 7(14),* 11-11.

Bimler, D. L. & Paramei, G. V. (2005). Bezold-Brücke effect in normal trichromats and protanopes. *Journal of the Optical Society of America A, 22(10),* 2120-2136.

Bjork, E.L. & Murray, J.T. (1977). Nature of input channels in visual processing. *Psychological Review 84 (5),* 472-484.

Bonnel, A. M. & Prinzmetal, W. (1998). Dividing attention between the colour and the shape of objects. *Perception &, Psychophysics, 60 (1),* 113-124.

Bouma, H. (1970). Interaction effects in parafoveal letter recognition. *Nature, 226,* 177-178.

Brazier, J. S., Desimone, R. & Ungerleider, L. G. (1993). Comparison of subcortical connections of inferior temporal and posterior parietal cortex in monkeys. *Visual Neuroscience, 10,* 59-72.

Broadbent, D. (1958). *Perception and Communication*. London, Pergamon Press.

Broadbent, D. & Broadbent, M.H.P. (1986). Encoding speed of visual features and the occurrence of illusory conjunctions. *Perception, 15 (5),*515-524.

Buchanan-Smith, H. M. & Heeley, D. W. (1993). Anisotropic axes in orientation perception are not retinotopically mapped. *Perception, 22(12),* 1389-1402.

Buck, S. L., Knight, R. F. & Bechtold, J. (2000). Opponent-color models and the influence of rod signals on the loci of unique hues. *Vision Research, 49(24),* 3333-3344.

Bundesen, C. (1987). Visual-attention - race models for selection from multielement displays. *Psychological Research, 49 (2-3),* 113-121.

Bundesen, C. (1991). Visual selection of features and objects - is location special - a reinterpretation of Nissen (1985) findings. *Perception &, Psychophysics, 50 (1),*87-89.

Bundesen, C. Shibuya, H. & Larsen, A. (1985). Visual selection from multielement displays: A model for parietal report. In M. I. Posner & O. S. M. Marin (Eds.), *Attention and performance X1 (*pp. 631-649). Hillsdale, NJ: Erlbaum.

Burr, D. C. & Morgan, M. J. (1997). Motion deblurring in human vision. *Proceedings of the Royal Society B: Biological Sciences. 264(1380), 431-436.*

Burr, D. C. & Santoro, L. (2001). Temporal integration of optic flow measured by contrast and coherence thresholds. *Vision Research, 41(15),* 1891-1899.

Campbell, F. W. C. & Robson, J. (1968). Application of Fourier analysis to the visibility of gratings. *Journal of Physiology 197,* 551-566.

Cassagrande, V. A. (1994). A third parallel visual pathway to primate area V1. *Trends in Neuroscience, 17(7),* 305-310.

Cavanagh, P. & Anstis, S. (1991). The contribution of color to motion in normal and color-deficient observers. *Vision Research, 32(12),* 2109-2148.

Cave, K. R. (1999). The FeatureGate model of visual selection. *Psychological Research, 62,* 182-194.

Cave, K. R. & Bishot, N. P. (1999). Visuospatial attention: Beyond a spotlight model. *Psychonomic Bulletin & Review, 6(2),* 204-223.

Cave, K. R. & Wolfe, J. M. (1990). Modeling the role of parallel processing in visual search. *Cognitive Psychology, 22,* 225-271.

Cave, K. R. & Zimmerman, J. M. (1997). Flexibility in spatial attention before and after practice. *Psychological Science, 8(5),* 399-403.

Chastain, G. (1982). Feature mislocalizations and misjudgements of intercharacter distance. *Psychological Research, 44,* 51-56.

Chen, L. & Zhou, W. (1997). Holes in illusory conjunctions. *Psychonomic Bulletin & Review, 4(4),* 507-511.

Cherry, E. C. (1953). Some experiments on the recognition of speech, with one and two ears. *Journal of the Acoustical Society of America, 25,* 975-979.

Chong, S. C. & Treisman, A. (2003). Representation of statistical properties. *Vision Research, 43,* 393-404.

Chong, S. C. & Treisman, A. (2004). Attentional spread in the statistical processing of visual displays. *Perception & Psychophysics, 66,* 1282-1294.

Chong, S. C. & Treisman, A. (2005a). Attentional spread in the statistical processing of visual displays. *Perception & Psychophysics, 67(1),* 1-13.

Chong, S. C. & Treisman, A. (2005b). Statistical processing: Computing the average size in perceptual groups. *Vision Research, 45,* 891-900.

Chung, S. T., Levi, D. M., & Legge, G. E. (2001). Spatial-frequency and contrast properties of crowding. *Vision Research, 41,* 1833-1850.

Cohen, A. & Ivry, R. B. (1989). Illusory conjunctions inside and outside the focus of attention. *Journal of Experimental Psychology, Human Perception and Performance, 15,* 650-663.

Cohen A. & Ivry, R. B. (1991). Density effects in conjunction search, evidence for coarse location mechanism of feature integration. *Journal of Experimental Psychology, Human Perception and Performance, 17,* 891–901.

Cohen, A. & Rafal, R. (1991). Attention and feature integrations: illusory conjunction in a patient with a parietal lobe lesion. *Psychological Science, 2,* 106-110.

Cohen, A. & Shoup, R. (2000). Response Selection Processes for Conjunctive Targets. *Journal of Experimental Psychology, Human Perception and Performance, 26(1),* 391-411.

Cohen, D. J. (1997). Visual detection and perceptual independence: Assessing color and form. *Perception & Psychophysics, 59(4),* 623-635.

Cohen, J. D. (1975). Temporal independence of the Bezold-Brücke hue shift. *Vision Research, 15,* 341-351.

Colegate, R. L., Hoffman, J. E. & Eriksen, C. W. (1973). Selective encoding from multielement visual displays. *Perception & Psychophysics, 14,* 217-224.

Coltheart, M. (1980). Iconic memory and visible persistence. *Perception & Psychophysics*, 27, 183-228.

Commission Internationale de l'Eclairage. (1971). *Colorimetry: Official Recommendations of the International Commission on Illumination.* CIE 15 (E-1.3.1). (Suppl. 2, 1978). Paris: Bureau Central de la CIE.

Corbetta, M. C., Miezen, F. M., Dobmeyer, S., Shulman, G. L. & Petersen, S. E. (1990). Attentional modulation of neural processing of shape, color, and velocity in humans. *Science, 248,* 1556-1559.

Corbetta, M., Miezin, F. M., Dobmeyer, S., Shulman, G. L., & Petersen, S. E. (1991). Selective and divided attention during visual discrimination of shape, color, and speed: Functional anatomy by positron emission tomography. *Journal of Neuroscience, 11,* 2383-2492.

Coren, S. & Keith, B. (1970). Bezold-Brücke effect: Pigment or neural locus? *Journal of the Optical Society of America A, 60,* 559-562.

Curcio, C. A., Sloan, K. R., Kalina, R. E. & Hendrickson, A. E. (1990). Human Photoreceptor Topography. *Journal of Comparative Neurology, 292(4), 497-523.*

Dakin, S. C. (1997). The detection of structure in glass patterns: psychophysics and computational models. *Vision Research, 37,* 2227-2246.

Dakin, S. C. & Watt, R. J. (1997). The computation of orientation statistics from texture. *Vision Reaearch, 37,* 3181-3192.

Damasio, A., Yamata, T., Damasio, H., Corbetta, J. & McKee, J. (1980). *Central achromatopsia: behavioral, anatomic and physiological aspects. Neurology, 30,* 1064-1071.

Davis, G. (2001). Between-object binding and visual attention. *Visual Cognition, 8(3-5),* 411-430.

Davis, G., Driver, J., Pavani, F & Shepherd, A. (2000). Reappraising the apparent cost of attending to two separate visual objects. *Vision Research, 40,* 1323-1332.

De Bruyn, B. & Orban, G. A. (1988). Human velocity and direction discrimination measured with random dot patterns. *Vision Research, 28,* 1323-1335.

Dehaene, S. (1989). Discriminability and dimensionality effects in visual search for featural conjunctions: A functional pop-out. *Perception & Psychophysics, 46 (1),* 72-80.

Desimone, R., Albright, T. D., Gross, C. G., & Bruce C. (1984). Stimulus-selective properties of inferior temporal neurons in the macaque. *Journal of Neuroscience, 4, 2051–2062.*

Desimone, R. & Duncan (1995). Neural Mechanisms of selective visual attention. *Annual Review of Neuroscience, 18,* 193-222.

Desimone, R., Schein, S. J., Moran, J. & Ungerleider, L. G. (1985). Contour, color and shape analysis beyond the striate cortex. *Vision Research,* 25, 441–452.

Deutsch, J. A., & Deutsch, D. (1963). Attention, Some theoretical considerations. *Psychological Review, 70,* 80-90.

De Valois, R. L., Albrecht, D. G., & Thorell, L. G. (1982). Spatial frequency selectivity of cells in macaque visual cortex. *Vision Research, 22,* 545–559.

De Yoe, E. A. & Van Essen, D. C. (1988). Concurrent processing streams in monkey visual cortex. *Trends in Neuroscience, 11,* 219–226.

Dixon, P. (1986). The category effect in visual detection and partial report. *Perception & Psychophysics, 38(3),* 286-295.

Donk , M. (1999). Illusory conjunctions are an illusion: The effects of target-nontarget similarity on conjunction and feature errors. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 1207-1233.

Donk, M. & Meinecke, C. (2001). Feature localization and identification. *Acta Psychologica, 106,* 97-119.

Driver, J. (2001). A selective review of selective attention research from the past century. *British Journal of Psychology,92(1),* 53-78.

Driver, J. & Mattingley, J. B. (1995). Selective attention in humans: normality and pathology. *Current Opinion in Neurobiology, 5,* 191-197.

Duncan, J. (1984). Selective attention and the organization of visual information. *Journal of Experimental Psychology, General, 113,* 501-517.

Duncan, J, (1988). Boundary conditions in parallel processing in human vision. *Perception 17*, 358.

Duncan, J. &, Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychological Review, 96*, 433-458.

Duncan, J. & Humphreys, G.W (1992). Beyond the search surface: Visual search and attentional engagement. *Journal of Experimental psychology: Human Perception and Performance, 18(2),* 578-588.

D'Zmura, M. (1991). Colour in visual search. *Vision Research 31(60, 951-966.*

D'Zmura, M., Krauskopf, J. & Lennie, P. (1987). Hue selectivity revealed by heterochromatic noise masking. *Investigative Ophthalmology and Visual Science, 28 (Suppl.),* 92.

Eckhorn, R., Bauer, R., Jordan, W., Brosch, M., Kruse, W., Munk, M. & Reitboeck, H. J. (1988). Coherent oscillations, a mechanism for feature linking in the visual cortex? *Biological Cybernetics, 60*, 121–130.

Egeth, H. (1966). Parallel versus serial processes in multidimensional stimulus discrimination. *Perception & Psychophysics, 1*, 245-252.

Egeth, H., Jonides, J., & Wall, S. (1972). Parallel processing of multielement displays. *Cognitive Psychology, 3,* 674-698.

Egeth, H., Virzi, A. & Garbart, H. (1984). Searching for conjunctively defined targets. *Perception and Performance, 23(1),* 263-277.

Eglin, M., Robertson, L. C. & Knight, R. T. (1989). Visual search performance in the neglect syndrome. *Journal of Cognitive Neuroscience, 1,* 372-385.

Ejima, Y. & Takahashi, S. (1984). Bezold-Brücke hue shift and nonlinearity in opponent-color process. *Vision Research, 24*, 1897-1904.

Enns, J. T. (2002). Visual binding in the standing wave illusion. *Psychonomic Bulletin & Review, 9(3),* 489-496.

Enns, J. T. & Rensink, R. A. (1990a). Scene-based properties influence visual search. *Science, 247*, 721-723.

Enns, J. T. & Rensink, R. A. (1990b). Sensitivity to three-dimensional orientation in visual search. *Psychological Science, 1,* 323-326.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics, 16*, 143-149.

Eriksen , B. A. & Hoffman, J. E. (1972). Temporal and spatial characteristics of selective encoding from visual displays. *Perception & Psychophysics, 12*, 201-204.

Eriksen, C. W. (1966). Independence of successive inputs and uncorrelated error in visual form perception. *Journal of Experimental Psychology, 72,* 26-35.

Eriksen, C. W. & Lappin, J. S. (1965). Internal perceptual system noise and redundancy in simultaneous inputs in form identification. *Psychonomic Science, 2,* 351-352.

Eriksen, C. W. & Spencer, T. (1969). Rate of information processing in visual perception: Some results and methodological considerations. *Journal of Experimental Psychology Monograph, 79,* 1-16.

Eriksen, C. W., & St. James, J. D. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception & Psychophysics, 40*, 225-240.

Eriksen C. W., & Yeh Y. (1985). Allocation of attention in the visual field. *Journal of Experimental Psychology, Human Perception and Performance, 11,* 583-597.

Eskandar, E. N., Richmond, B. J. & Optican, L. M. (1992). Role of inferior temporal neurons in visual memory: 1. Temporal encoding of information about visual images, recalled images, and behavioural context. *Journal of Neurophysiology, 68(4),* 1277-1295.

Estermann, M., McGinchey-Barroth, R. & Milberg, W. P. (2000). Parallel and serial search in hemispatial neglect: evidence for preserved preattentive but impaired attentive processing. *Neuropsychology, 14,* 599-611.

Estes, W. K. (1956). The problem of inference from curves based on group data. *Psychological Bulletin, 53,* 134-140.

Estes, W. K. (1972). Interaction of signal and background variables in visual processing. *Perception & Psychophysics, 12,* 278-286.

Estes, W. K. (1974). Redundancy of noise elements and signals in visual detection of letters. *Perception & Psychophysics, 16,* 53-60.

Estes, W. K. (1975). The locus of inferential and perceptual processes in letter identification. *Journal of Experimental Psychology, 104,* 122-145.

Estes, W. K. & Taylor, H. A. (1964). A detection method and probabilistic models for assessing information processing from brief visual displays. *Proceedings of the National Academy of Science, 52,* 446-454.

Eurich, C. W. & Schwegler, H. (1997). Coarse coding: Calculation of the resolution achieved by a population of large receptive field neurons. *Biological Cybernetics, 76,* 357-363.

Fanini A., Nobre A.C. & Chelazzi, L. (2006). Selecting and ignoring the component features of a visual object: A negative priming paradigm. *Visual Cognition, 14(4-8),* 584-618.

Farah, M. J. (1990). *Visual agnosia: Disorders of object recognition and what they tell us about normal vision.* Cambridge, Mass: MIT Press.

Farah, M. J. (1994). Neuropsychological inference with an interactive brain: A critique of the "locality" assumption. *Behavioural and Brain Sciences, 17(1),* 43-104.

Farmer, E. & Taylor, R. (1980). Visual search through color displays: Effects of target-background similarity and background uniformity. *Perception & Psychophysics, 27,* 267-272.

Felisberti, F. M., Solomon, J. A. & Morgan, M. J. (2005). The role of target salience in crowding. *Perception, 34(7),* 823-833.

Fodor, J. A. & Pylyshyn, Z. W. (1988). Connectionism and cognitive architecture, a critical analysis. *Cognition, 28,* 3–71.

Folk, C. L. & Annett, S. (1994). Do locally defined feature discontinuities capture attention? *Perception & Psychophysics, 56,* 277-287.

Folk, C. L. & Egeth, H. (1989). Does the identification of simple features require serial processing? *Journal of Experimental Psychology: Human Perception &, Performance, 15,* 97–110.

Foster, D. H. & Ward, P. A. (1991). Horizontal-vertical filters in early vision predict anomalous line-orientation frequencies. *Proceedings of the Royal Society, London, B, 243,* 83-86.

Freeman, J. & Pelli, D. (2007). An escape from crowding. *Journal of Vision, 7(2),* 1-14.

Friedman-Hill, S. R., Robertson, L. C. & Treisman, A. (1995). Parietal contributions to visual feature binding: Evidence from a patient with bilateral lesions. *Science, 269,* 853-855.

Fryklund, J. (1975). Effects of cued-set spatial arrangement and target-background similarity in the partial report paradigm. *Perception & Psychophysics, 17,* 375-386.

Garner, W. R. (1974). *The processing of information and structure.* Protomac, MD: Erlbaum.

Garner, W. R. (1978). Aspects of a stimulus: Features, dimensions, and configurations. In E. Rosch & B. B. Lloyd (Eds.), *Cognition and categorization.* Hillsdale, NJ: Erlbaum.

Garson, J. W. (2001). (Dis)solving the binding problem. *Philosophical Psychology, 14(4),* 381-392.

Gegenfurtner, K. R., Kiper, D. C. & Fenstemaker, S. B. (1996). Processing of color, form, and motion in macaque area V2. *Visual Neuroscience, 13,* 161-172.

Geusebroek, J. M., van den Boomgaard, R., Smeulders, A. W. M., Geerts, H. (2001). "Color invariance". *Pattern Analysis and Machine Intelligence, IEEE Transactions, 23 (12):* 1338-1350.

Ghose, G. M. & Maunsell, J. (1999). Specialized representations in visual cortex, a role for binding? *Neuron, 24*, 79–85.

Gibson, B. S. & Egeth, H. (1994). Inhibition and disinhibition of return: Evidence from temporal order judgements. *Perception & Psychophysics, 56(6),* 669-680.

Gibson, B. S. & Jiang, Y. (1998). Surprise! An unexpected color singleton does not capture attention in visual search. *Psychological Science, 9*, 176-182.

Goldman-Rakic, P. S. (1987). Circuitry of primate prefrontal cortex and regulation of behaviour by representational knowledge. In: F. Plum & V. B. Mountcastle. (Eds.). (1987). *Handbook of physiology*, Section1: *The nervous system*, volume 5: *Higher functions of the brain*, pp 373-417. Bethesda, Md: American Psychological Society.

Goodale, M. A. & Milner, A. D., (1992). Separate visual pathways for perception and action. *Trends in Neurosciences, 15,* 20-25.

Goolkasian, P. & Bojco, A. (2001). Location constancy and its effect on visual selection. *Spatial Vision, 14(2),* 175-199.

Gordon, J. & Abramov, I. (1977). Color vision in the peripheral retina. II. Hue and Saturation. *Journal of the Optical Society of America, 67(2), 202-207.*

Graham, N. & Hood, D. C. (1992). Quantal noise and decision rules in dynamic models of light adaption. *Vision Research, 32(4),* 779-787.

Green, M. (1991). Visual search, visual streams, and visual architectures. *Perception & Psychophysics, 50(4),* 388-403.

Green, M. (1992). Visual search, detection, identification and localization. *Perception, 21*, 765–777.

Gross, C. G. (1973). Inferotemporal cortex and vision. In E. Stellar & J. M. Sprague (Eds.). (1973). *Progress in physiological psychology*, pp 77-123. New York: Academic Press.

Grossberg, S., Mingolla, E., & Ross, W. D. (1994). A neural theory of attentive visual search: Interactions of boundary, surface, spatial, and object representations. *Psychological Review, 101*(3), 470-489.

Harms, L. & Bundensen, C. (1983). Color segregation and selective attention in a nonsearch task. *Perception & Psychophysics, 33(1),* 11-19.

Hartridge, H. (1918). Chromatic aberration and resolving power of the eye. *Journal of Physiology, 52*, 175-246.

Harwerth, R. S., Fredenberg, P. M. & Smith, E. L. III. (2003). Temporal integration for stereoscopic vision. *Vision Research, 43(5),* 505-517.

Hasselmo, M. E., Rolls, E. T. & Bayliss, G. C. (1989). The role of expression and identity in the face-selective responses of neurons in the temporal visual cortex of the monkey. *Behavioural Brain Research, 32,* 203-218.

Haxby, J. V., Grady, C. L., Horwitz, B, Ungerleider, L. G., Mishkin, M., Carson, R. E., Herscovitch, P., Schapiro, M. B. & Rapoport, S. I. (1991). Dissociation of object and spatial visual processing pathways in human extrastriate cortex. *Proceedings of the National Academy of Sciences of the United States of America, 88,* 1621-1625.

Hayes, K. J. (1953). The backward curve: a method for the study of learning. *Psychological Review, 60,* 269-275.

Hazeltine,R. E., Prinzmetal, W. & Elliott, K. (1997). If it's not there, where is it? Locating illusory conjunctions. *Journal of Experimental Psychology: Human Perception and Performance, 23(1),* 263-277.

He, J. J. & Nakayama, K. (1992). Surfaces versus features in visual search. *Nature, 359(6392),* 231-233.

Heeley, D. W. & Buchanan-Smith, H. M. (1990). Recognition of stimulus orientation. *Vision Research, 30,* 1429-1437.

van der Heijden, A. H. C., van der Geest, J. N., de Leeuw, F., Krikke, K. & Müsseler, J. (1999). Sources of position-perception error for small isolated targets. *Psychological Research, 62,* 20-35.

Hering, E. (1905). Outlines of a theory of the light sense. Translated by L.M. Hurvich and D. Jameson. (1965). Cambridge, Mass: Harvard University Press.

Herzog, M. H. & Koch, C. (2001). Seeing an invisible object: Feature inheritance and shine-through. *Proceedings of the National Academy of Science, USA, 88,* 4271-4275.

Hinton, G. E. (1981). Shape representation in parallel systems. In *Proceedings, 7th International Joint Conference on Artificial Intelligence,* pp. 1088-1096. Vancouver, BC, Canada.

Hinton, G. E. & Lang, K. J. (1985). Shape recognition and illusory conjunctions. *Proceedings of the Ninth International Joint Conference on AI, Los Angeles,* pp. 252-259.

Hoffman, J. E. (1978). Search through a sequentially presented visual display. *Perception & Psychophysics, 23,* 1-11.

Holcombe, A. O. & Cavanagh, P. (2001). Early binding of feature pairs for visual perception. *Nature Neuroscience, 4(2),* 127-128.

Hole, G. J., (1996). Decay and interference effects in visuospatial short-term memory. *Perception, 25,* 53-64.

Horowitz, T. S. & Wolfe, J. M. (2001). Search for multiple targets: Remember the targets, forget the search. *Perception & Psychophysics, 63,* 272-285.

Huang, L. & Pashler, H. (2002). Symmetry detection and visual attention: A "binary-map" hypothesis. *Vision Research, 42,* 1421-1430.

Huang, L. & Pashler, H. (2007). A Boolean map theory of visual attention. *Psychological Review, 114,* 599-631.

Hubbard, T. L. (1995). Some effects of representational friction, target size, and memory averaging on memory for vertically moving targets. *Canadian Journal of Experimental Psychology, 52(1),* 44-49.

Hubbard, L. & Ruppel, S. E. (2000). Spatial memory averaging, the landmark attraction effect, and representational gravity. *Psychological Research, 64,* 41-55.

Hubel, D. & Livingstone, M. S. (1987). Segregation of form, color, and stereopsis in primate area 18. *Journal of Neuroscience, 7,* 3378-3415.

Hubel, D. & Weisel, T. N. (1960). Receptive fields of optic nerve fibres in the spider monkey. *Journal of Physiology, 154,* 572-580.

Huckauf, A. (2007). Task set determines the amount of crowding. *Psychological Research, 71(6),* 646-652.

Hummel, J. E. & Holyoak, K. J. (1997). Distributed representations of structure: A theory of analogical access and mapping. *Psychological Review, 104,* 427-466.

Humphreys, G. W., Cinel, C., Wolfe, J., Olson, A. & Klempen, N. (2000). Fractionating the binding process: neurophysiological evidence distinguishing binding of form from binding of surface features. *Vision Research, 40,* 1569-1596.

Humphreys, G. W. & Riddoch, M. J. (1993). Interaction between space-based and object-based systems revealed through neuropsychology. In D. E. Meyer & S. Kornblum (Ed.), *Attention and Performance X1V.* Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Hurvich, L. M. (1981). *Colour Vision.* Boston, MA: Sinauer Associates.

Hurvich, L. M. & Jameson, D. (1955) Some quantitative aspects of an opponent-colors theory. 11. Brightness, saturation, and hue in normal and dichromatic vision. *Journal of the Optical Society of America, 45,* 602-616.

Hurvich, L. M. & Jameson, D. (1957). An opponent-process theory of colour vision. *Psychological Review, 64,* 384-404.

Huttenlocher, J., Hedges, L. V. & Duncan, D. (1991). Categories and particulars: Prototype effects in estimating spatial location. *Psychological Review, 98(3),* 352-376.

Imhoff, S. M., Volbrecht, V. J. & Nerger, J. L. (2004). A new look at the Bezolde-Brücke hue shift in the peripheral retina. *Vision Research, 44(16),* 1891-1906.

Intrilligator, J. & Cavanagh, P. (2001). The spatial resolution of visual attention. *Cognitive Psychology, 43(3),* 171-216.

Jacobs, A. M., Nazir, T. A. & Heller, O. (1989). Perception of lowercase letters in peripheral vision: A discrimination matrix based on saccade latencies. *Perception & Psychophysics, 46(1),* 95-102.

Jameson, D. & Hurvich, L. (1955). Some quantative aspects of an opponent colors theory – II: Brightness, saturation, and hue in normal and dichromatic vision. *Journal of the Optical Society of America, 45,* 602-616.

Johnson, M. K. & Raye, C. L. (1981). Reality monitoring. *Psychological Review, 88(1),* 67-85.

Johnston, J. C. & Pashler, H. (1990). Close binding if identity and location in visual feature perception. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 843-856.

Jonides, J. (1981). Voluntary versus automatic control over the mind's eye's movement. In J.B. Long & A. D. Baddeley (Eds.), *Attention and performance 1X* (pp 187-203). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Jonides, J. (1983). Further toward a model of the mind's eye movement. *Bulletin of the Psychonomic Society, 21,* 247-250.

Jonides, J., & Yantis, S. (1988). Uniqueness of abrupt visual onset in capturing attention. *Perception & Psychophysics, 43,* 346-354.

Kadoya, S., Wolin, L. R. & Massopust, L. C. Jr. (1971). Photically evoked unit activity in the tectum opticum of the squirrel monkey. *Journal of Computational Neuroscience, 142(4),* 495-508.

Kahneman, D. (1973). *Attention and effort.* Englewood Cliffs, NJ: Prentice Hall.

Kaster, S., De Weerd, P., Pinsk, M. A., Elizondo, M. I., Desimone, R & Ungerleider, L. G. (2001). Modulation of sensory suppression: Implications for receptive field sizes in the human visual cortex. *Journal of Neurophysiology, 86(3),* 1398-1411.

Keele, S. W., Cohen, A., Ivry, R., Liotti, M. & Yee, P. (1988). *Journal of Experimental Psychology: Human Perception and Performance, 14,* 444-452.

Kerzel, D. (2002). Memory for the position of stationary objects: disentangling foveal bias and memory averaging. *Vision Research, 42,* 159-167.

Khurana, B. (1998) Visual Structure and the Integration of Form and Color Information. *Journal of Experimental Psychology: Human Perception and Performance, 24(6),* 1766-1785.

Kim, M. & Robertson, L. C. (2001). Implicit Representations of Space after Bilateral Parietal Lobe Damage. *Journal of Cognitive Neuroscience, 13(8),* 1080-1087.

Kinchla, R. A. (1974). Detecting targets in multi-element arrays, A confusability model. *Perception & Psychophysics, 15,* 149-158.

Kishto, B. N. (1965). The colour stereoscopic effect. *Vision Research, 5,* 313-329.

Klein, R. M. & Dukewich, K. (2006). Does the inspector have a memory? *Visual Cognition, 14(4-8),* 648-667.

Klein, S. A. & Levi, D. M. (1987). Position sense of the peripheral retina. *Journal of the Optical Society of America, Part A, 4,* 1544-1553.

Koch, C. & Ullman, S. (1985) Shifts in selective visual attention: Towards the underlying neural circuitry. *Human Neurobiology, 4,* 219-227.

König, A, (1903). *Phsyiogische Optik.* Leipzig:Johann Ambrosius Barth. In: Middleton, W. E. K. & Holmes, M. C. (1949). The Apparent Colors of Surfaces of Small Subtense – A Preliminary Report. *Journal of the Optical Society of America, 39(7),* 582-592

Kontsevich, L. L. & Tyler, C. W. (1999). Distraction of attention and the slope of the psychometric function. *Journal of the Optical Society of America A, 16,* 217-222.

Kooi, F. L., Toet, A., Tripathy, S. P. & Levi, D. M. (1994). The effect of similarity and duration on spatial interaction in peripheral vision. *Spatial Vision, 8(2),* 255-279.

Kosslyn, S. M. (1987). Seeing and imagining in the cerebral hemispheres: A computational approach. *Psychological Review, 94,* 148-175.

Kosslyn, S. M., Alpert, N. M., Thompson, W. L., Malikovic, V., Weise, S. B., Chabris, C. F., Hamilton, S. E., Rauvh, S. L. & Buonanno, S., (1993). Visual Mental Imagery Activates Topographically Organized Visual Cortex, PET Investigations. *Journal of Cognitive Neuroscience, 5 (3),* 263-287.

Kowler, E. & Blaser, E. (1995). The accuracy and precision of saccades to small and large targets. *Vision Research, 35(12),* 1741-1754.

Krauskopf, J., Williams, D. R. & Heeley, D. W. (1982). Cardinal Direction of color space. *Vision Research, 22,* 1123-1131.

Krauskopf, J., Williams, D. R., Mandler, M. B. & Brown, A. M. (1986). Higher order color mechanisms. *Vision Research, 26.* 23-32.

Krumhansl, C. A. & Thomas, E. A. C. (1976). Extracting identity and location information from briefly presented letter arrays. *Perception & Psychophysics, 20,* 243-258.

LaBerge, D. (1975). *Attentional processing: The brain's art of mindfulness.* Cambridge, MA: Harvard University Press.

LaBerge, D. (1995). *Attentional Processing.* Cambridge, MA: Harvard University Press.

LaBerge, D. & Brown, V. (1986). Variations in size of the visual field in which targets are presented: An attentional range effect. *Perception & Psychophysics 40,* 188-200.

LaBerge, D. & Buchsbaum, M. S. (1990). Positron emission tomography measurements of pulvinar activity during an attentional task. *Journal of Neuroscience, 10,* 613-619.

Laeng, B., Peters, M. & McCabe, B. (1998). Memory for locations within regions: Spatial bias and visual hemifield differences. *Memory & Cognition, 26,* 97-107.

Lavie, N. (1997). Visual feature integration and focused attention: Response competition from multiple distractor features. *Perception & Psychophysics, 59, 543-556.*

Lavie, N. (2005). Distracted and confused?: Selective attention under load. *Trends in Cognitive Sciences, 9(2),* 75-82.

Lavie, N. & Tsal, Y. (1994). Perceptual load as a major determinant of the locus of selection in visual attention. *Perception & psychophysics, 56,* 183-197.

Leber, A. B. & Egeth, H. E. (2006). Attention on autopilot: Past experience and attentional set. *Visual Cognition, 14(4-8),* 565-583.

Lee, , D. K., Itti, L., Koch, C. & Braun, J. (1999). Attention activates winner-takes-all competition among visual filters. *Nature Neuroscience, 2,* 375-381.

Lehky, D. R. & Sejnowski, T. J. (1988). Network model of shape-from-shading: neural function arises from both receptive and projective fields. *Nature, 333,* 452-4.

Lennie, P., Trevarthen, C, Van Essen, D. & Wassle, H. (1990). Parallel processing of visual information. In L. Spillman & J. S. Werner (Eds.), *Visual perception: The neurophysiological foundations,* (pp 103-128). San Diego, CA: Academic Press.

Leonards, U., Sunaert, S., Van Hecke, P. & Orban, G. A. (2000). Attention Mechanisms in Visual Search – An fMRI study. *Journal of Cognitive Neuroscience, 12: Supplement 2,* 61-75.

Levi, D. M., Hariharan, S. & Klein, S. A. (2002). Suppressive and facilitatory spatial interactions in peripheral vision: Peripheral crowding is neither size invariant nor simple contrast masking. *Journal of Vision, 2(2),* 167-177.

Levi, D. M. &. Klein, S. A. (1989). Both separation and eccentricity can limit precise position judgements: A reply to Morgan & Watt. *Vision Research, 28,* 1463-1469.

Levi, D. M., Klein , S. A.& Aitsebaomo, A. P. (1985). Vernier acuity, crowding and cortical magnification. *Vision Research, 25,* 963-977.

Livingstone, M. S. & Hubel, D. H. (1987). Psychophysical evidence for separate channels for the perception of form, colour, movement and depth. *Journal of Neuroscience,* 7, *3416-3468.*

Locke, J. (1690). *Essay concerning human understanding.* London: Thomas Basset.

Logan, G. D. (1975). On the independence of naming and locating masked targets in visual search. *Canadian Journal of Psychology, 29,* 51-58.

Louie, E. G., Bressler, D. W. & Whitney, D. (2007). Holistic crowding: selective interference between configural representations of faces in crowded scenes. *Journal of Vision, 7(24),* 11-21.

Luce, R. D. (1977). The choice axiom after twenty years. *Journal of Mathematical Psychology, 15,* 215-233.

Luck, S. J., Fan, S., & Hillyard, S. A. (1993). Attention-related modulation of sensory-evoked brain activity in a visual search task. *Journal of Cognitive Neuroscience, 5,* 188-195.

Luria, A. R. (1959). Disorders of "simultaneous perception" in a case of bilateral occipito-parietal brain injury. *Brain, 83,* 437-449.

Luria, S. M. (1967). Color-name as a function of stimulus-intensity and duration. *American Journal of Psychology, 80,* 14-27.

Magnussen, S., Asplund, R., Dyrnes, S. & Greenlee, M. W. (1988). Spatial selectivity of the short-term memory image. *Perception, 17(3),* A54-A55.

Magnussen, S., Greenlee, M. W., Asplund, R. & Dyrnes, S., (1991). Stimulus-specific mechanisms of visual short- term memory. *Vision Research, 31,* 1213-1219.

von der Malsburg, C. (1981). Internal report. Max-Plank Institute for Biophysical Chemistry, Göttingen, Germany.

Mangun, G. R., Hillyard, S. A., & Luck, S. J. (1993). Electrocortical substrates of visual selective attention. In D. Meyer, S. Kornblum (Eds.), *Attention and Performance XIV* (pp. 219-143). Cambridge, MA, MIT Press.

Marshall, J. C. (1984). *Human Cognitive Neuropsychology: a textbook with readings. Hove: Psychology Press.*

Marshall, J.C., Newcombe, F. (1984). Putative problems and pure progress in neuropsychological single-case studies. *Journal of Clinical Neurophychology, 6(1),* 65-70.

Mateef, S. & Gourevich, A. (1983). Peripheral vision and perceived visual direction. *Biological Cybernetics, 49(2),* 111-118.

McCrae, S.M., Buxbaum, L.J. & Coslett, H. B. (2006). Illusory conjunctions in simultanagnosia: Coarse coding of visual feature location? *Neuropsychologia, 44,* 1724-1736.

McLeod, P., Driver, J. & Crisp, J. (1988). Visual search for conjunctions of movement and form in parallel. *Nature, 332,* 154-155.

Merigan, W. H. & Maunsell, J. H. R. (1993). How parallel are the primate visual pathways? *Annual Review of Neuroscience, 16,* 369-402.

Merigan, W., Freeman, A. & Meyers, S. P. (1997). Parallel processing streams in human visual cortex. *Neuroreport, 8(18),* 3985-3991.

Middleton, W. E. K. & Holmes, M. C. (1949). The Apparent Colors of Surfaces of Small Subtense – A Preliminary Report. *Journal of the Optical Society of America, 39(7),* 582-592.

Middleton. W. E. K. & Mayo, E. G. (1952). The appearance of colours in twilight. *Journal of the Optical Society of America, 42,* 116-121.

Milner, A. D. & Goodale, M. A. (Eds.) (1995). *The visual brain in action.* Oxford: Oxford Science Publications.

Milner, A. D. & Goodale, M. A. (2007). Two visual systems re-viewed. *Neuropsychologia, 46(3),* 774-785.

Mollon, J. D. (1982). A taxonomy of tritanopias. *Documenta Opthalmologica, Proceedings Series, 33,* 87-101.

Mollon, J. D., Astell, S. & Cavonius, C. R. (1992). A Reduction in Stimulus Duration can Improve Wavelength Discriminations Mediated by Short-wave Cones. *Vision Research, 32(4),* 745-755.

Mollon, J. D. & Polden, P. G. (1975). Colour illusion and evidence for interaction between cone mechanisms. *Nature, 258,* 421-422.

Moraglia, G, Maloney, K., Fekete, E. & Al-Basi, K. (1989). Visual Search along the colour dimension. *Canadian Journal of psychology, 43,* 1-12.

Morales, D. & Pashler, H. (1999). No role for colour in symmetry perception. *Nature, 309,* 115-116.

Moran , J. & Desimone, R. (1985). Selective attention gates visual processing in the extrastriate cortex. *Science, 229,* 782-784.

Mordkoff, J. T. & Yantis, S. (1993). Dividing attention between color and shape: Evidence for coactivation. *Perception &Psychophysics 53(4), 357-366.*

Mordkoff, J. T. & Halterman, R. (2008). Feature integration without visual attention: Evidence from the correlated flankers task. *Psychonomic Bulletin & Review, 15(2),* 385-389.

Morgan, M.J., Hole, G.J. & Glennerster, A. (1990). Biases and sensitivities in geometrical illusions. *Vision Research 30(11),* 1793-1810.

Morgan, M. J., Ward, R. M. & Castet, E. (1998). Visual search for a tilted target: Tests of spatial uncertainty models. *Quarterly Journal of Experimental Psychology A, 51,* 347-370.

Motter, B. C. & Simoni, D. A. (2007). The roles of cortical image separation and size in active visual search performance. *Journal of Vision, 7(6),* 1-15.

Müller, H. J., Humphreys, G. W., & Donnelly, N. (1994). Search via Recursive Rejection (SERR): Visual search for single and dual form-conjunction targets. *Journal of Experimental Psychology: Human Perception & Performance, 20,* 235-258.

Nagy, A. L. (1979). Unique hues are not invariant with brief stimulus durations. *Vision Research, 19,* 1427-1432.

Nagy, A. L. (1980). Short-flash Bezold-Brücke hue shifts. *Vision Research, 20, 361-368.*

Nagy, A. L. & Sanches, R. R. (1990). Critical color differences determined with a visual search task. *Journal of the Optical Society of America A, 7,* 1209-1217.

Nakayama, K. (1990). The iconic bottleneck and the tenuous link between early visual processing and perception. In: C. Blakemore (Ed). *Vision: Coding and efficiency* (pp. 411-422). Cambridge: Cambridge University Press.

Nakayama, K., & Silverman, G. H (1986b). Serial and parallel encoding of visual feature conjunctions. *Investigative Ophthalmology and Visual Science, 27 (supplement),* 182.

Navon, D. & Erlich, B. (1995). Illusory conjunctions: Does inattention really matter? *Cognitive Psychology, 29,* 59-83.

Nelson, T. O. & Chaiklin, S. (1980). Immediate memory for spatial location. *Journal of Experimental Psychology: Human Learning and Memory, 6,*529-545.

Neisser, U. (1967). *Cognitive Psychology*. New York: Appleton-Century-Crofts.

Neisser, U. (1985). Towards an ecologically oriented cognitive science. In T. M. Schlecter & M. P. Toglia (Eds.), *New directions in cognitive science,* (pp. 17-32), Norwood, NJ: Ablex.

Newby, E. A, & Rock, I. (2001). Location and attention. *Quarterly Journal of Experimental Psychology, 54A,* 155-168.

Newcombe, F.& Russell, W. R. (1969). Dissociated visual perceptual and spatial deficits in focal lesions of the right hemisphere. *Journal of Neurology, Neurosurgery & Psychiatry, 32,* 73-81.

Newsome, W. T., Wurtz, R. H. & Komatsu, H. (1988). Relation if cortical areas MT and MST to pursuit eye movements: II. Differentiation of retinal from extraretinal inputs. *Journal of Neurophysiology, 60,* 604-620.

Nijhawan, R. (1997). Is retinal disparity really retinal? *Investigative Opthalmology & Visual Science, 38(4),* 4216-4216.

Nissen, M. J. (1985). Accessing features and objects: Is location special? In, Posner, M.I., Marin, O.S.M. (Eds.). *Attention and Performance XI.* Hillsdale, LEA.

Norman, D.A. (1968). Toward a theory of memory and attention. *Psychological Review, 75,* 522-536.

Northdurft, H. C. (1993) Saliency effects across dimensions in visual search. *Vision Research, 33,* 839-844.

Northdurft, H. C. (2006). Salience and target selection in visual search. *Visual Cognition, 14(4/5/6/7/8),* 514-542.

Oliva, A. & Torralba, A. (2001). Modeling the shape of the scene: A holistic representation of the spatial envelope. *International Journal of Computer Vision, 42,* 145-175.

Oliva, A. & Torralba, A. (2007). The role of context in object recognition. *Trends in Cognitive Sciences, 11(12),* 520-527.

O'Regan, J. K. (1984). Retinal versus extraretinal influences in flash localization during saccadic eye movements in the presence of a visible background. *Perception & Psychophysics, 36,* 1-14.

Owsley, C, Burton-Danner, K., & Jackson, G. R. (2000). Ageing and Spatial Localization during Feature Search. *Gerontology, 46,* 300-305.

O'Regan, J. K. & Noë, A. (2001). A sensorimotor account of vision and visual consciousness. *Behaviour and Brain Sciences, 24(5),* 939-1011.

Palmer, J, Ames, C. T. & Lindsey, D. T. (1993). Measuring the effect of attention on simple visual search. *Journal of Experimental Psychology: Human Perception and Performance, 19,* 108-130.

Parkes, L., Lund, J., Angelucci, A., Solomon, J. A. & Morgan, M. (2001). Compulsory averaging of crowded orientation signals in human vision. *Nature neuroscience, 4,* 739-744.

Parry, N. R. A., McKeefry, D. J. & Murray, I. J. (2006). Variant and invariant color perception in the near peripheral retina. *Journal of the Optical Society of America A – Optics Image Science and Vision, 23(7),* 1586-1597.

Pashler, H. E. (1987a). Detecting conjunctions of color and form, Reassessing the serial search hypothesis. *Perception & Psychophysics, 41,* 191-201.

Pashler, H. E. (1987b). Target-distractor discriminability in visual search. *Perception & Psychophysics, 41,* 285-292.

Pashler H. & Badgio, P. C. (1987). Visual attention and stimulus identification. *Journal of Experimental Psychology: Human Perception and Performance, 11,* 105-121.

Pelli, G. G. (1980). *Effects of visual noise.* Ph.D. thesis, Cambridge University.

Pelli, D. G. (1985). Uncertainty explains many aspects of visual contrast detection and discrimination. *Journal of the Optical Society of America A, 2(9),* 1508-1532.

Pelli, D. G., Palomares, M. & Majaj, N. J. (2004). Crowding is unlike ordinary masking: Distinguishing feature integration from detection, *Journal of Vision, 4(12),* 1136-1169.

Perrett, D. I., Oram, M. W., Harries, M. H., Bevan, R., Hietanen, J. K., Benson, P. J. & Thomas, S. (1991). Viewer-centred and object-centred coding of heads in the macaque temporal cortex. *Experimental Brain Research, 86,* 159-173.

Perry, V. H., Oehler, R. & Cowey, A. (1984). Retinal ganglion cells that project to the dorsal lateral geniculate nucleus in the macaque monkey. *Neuroscience, 12(4),* 1101-1123.

Petrov, Y. & Popple, A. V. (2007). Crowding is directed to the fovea and preserves only feature contrast. *Journal of Vision, 7(2),* 1-9.

Põder, E. (2006). Crowding, feature integration, and two kinds of "attention". *Journal of Vision, 6,* 163-169.

Põder, E. (2007). Effect of color pop-out on the recognition of letters in crowded conditions. *Psychological Research, 71,* 615-715.

Poirier, F. J. A. M. & Frost, B. J. (2005). Global orientation aftereffect in multi-attribute displays: implications for the binding problem. *Vision Research, 45(4),* 497-506.

Pomerantz, J. R. (2006). Colour as a Gestalt: Pop out with basic features and with conjunctions. *Visual Cognition, 14(4,5,6,7,8),* 619-628.

Posner, M. I. (1978). *Chronometric explorations of mind.* Hilsdale NJ: Lawrence Erlbaum Associates.

Posner, M. I. & Dehaene, S. (1994). Attentional Networks. *Trends in Neurosciences, 17,* 75-79.

Posner, M. I., Snyder, C. R., , Davidson, B. J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology, General, 109,* 160-174.

Pratt , J. & Abrams, R. A. (1995). Inhibition of return to successively cued spatial locations. *Journal of Experimental Psychology: Human Perception and Performance, 21(6),* 1343-1353.

Pridmore, R. W. (1999). Bezold-Brücke hue-shift as functions of luminance level, luminance ratio, interstimulus interval and adapting white for aperture and object colors. *Vision Research, 39,* 3873-3891.

Prinzmetal, W. (1981). Principles of feature integration in visual perception. *Perception & Psychophysics, 30,* 330-340.

Prinzmetal, W. (2005). Location perception: The X-Files parable. *Perception & Psychophysics, 67(1),* 48-71.

Prinzmetal, W., Amiri, H., Allen, K., & Edwards, T. (1998). Phenomenology of Attention, 1. Color, Location, Orientation, and Spatial Frequency. *Journal of Experimental Psychology: Human Perception and Performance, 24(1),* 261-282.

Prinzmetal, W., Henderson, D. & Ivry, R. B. (1995). Loosening the constraints on illusory conjunctions: The role of exposure duration and attention. *Journal of Experimental Psychology: Human Perception and Performance, 21,*1362-1375.

Prinzmetal, W., Ivry, R. B., Beck, D. & Shimizu, N. (2002). A Measurement Theory of Illusory Conjunctions. *Journal of Experimental Psychology: Human Perception and Performance, 28(2),* 251-269.

Prinzmetal, W. & Keysar, (1989). Functional Theory of Illusory Conjunctions and Neon Colors. *Journal of Experimental Psychology: General, 118(2),* 165-190.

Prinzmetal, W., McCool, C. & Park, S. (2005). Attention: Reaction time and accuracy reveal different mechanisms. *Journal of Experimental Psychology: General, 134(1),* 73-92.

Prinzmetal, W. & Mills-Wright, M. (1984). Cognitive and linguistic factors affect feature integration. *Cognitive Psychology, 16,* 305-340.

Prinzmetal, W., Nwachuku, I., Bodanski, L., Blumenfeld, L. & Shimizu, N. (1997). The phenomenology of attention part 2: Brightness and contrast. *Consciousness and Cognition, 6,* 372-412.

Prinzmetal, W. & Taylor, N. (2006). Color singleton pop-out does not always poop out: An alternative to visual search. *Psychonomic Bulletin & Review, 13(4),* 576-580.

Prinzmetal W., Treiman, R. & Rho, C. (1986). How to see a reading unit. *Journal of Memory & Language, 25,* 461-475.

Purdy, D. (1931a). On the saturations and chromatic thresholds of the spectral colours. *British Journal of Psychology,* 21, *282-313.*

Purdy, D. (1931b). Spectral hue as a function of intensity. *American Journal of Psychology, 43,* 541-559.

Rabbitt, P. M. A. (1967). Learning to ignore irrelevant information. *American Journal of Psychology, 80,* 1-13.

Ramachandran, V . S. (1988). Perception of shape from shading. *Nature, 331,* 163-165.

Rapp, B. C. (1992). The nature of sublexical orthographic organization: The bigram trough hypothesis examined. *Journal of memory and Language, 31,* 33-53.

Ratcliff, R. (1978). A theory of memory retrieval. *Psychological Review, 85(2),* 59-108.

Regan, D. (1985). Storage of spatial-frequency information and spatial-frequency discrimination. *Journal of the Optical Society of America, A, 2,* 619-621.

Reijnen, E., Rich, A. N., Van Wert , M. J. & Wolfe, J. M. (2007). The role of categorical boundaries in visual search for colour. *Journal of Vision, 7(9),* 681.

Remington, R., & Pierce, L. (1984). Moving attention: Evidence for time-invariant shifts of visual selective attention. *Perception & Psychophysics, 35,* 393-399.

Riefer, D. M. & Batchelder, W. H. (1988). Multinomial Modelling and the measurement of cognitive processes. *Psychological Review 95,* 318-339.

Rizzo, M. & Vecera, S.P. (2002). Psychoanatomical substrates of Bálint's syndrome. *Journal of Neurology, Neurosurgery & Psychiatry, 72,* 162-178.

Ro, T. & Rafal, R. D. (1999). Components of reflexive visual orienting to moving objects. *Perception & Psychophysics, 61,* 826-836.

Robertson, L. C. 2003. Binding, Spatial Attention and Perceptual Awareness. *Nature Reviews: Neuroscience, 4,* 93-102.

Robertson, L. C., Treisman, A., Freidman-Hill, S. R. & Grabowecky, M. (1997). The interaction of spatial and object pathways: Evidence from Bálint's syndrome. *Journal of Cognitive Neuroscience, 9,* 254-276.

Roggerveen, A. B., Kingston, A. & Enns, J. T. (2004). Influence of inter-item symmetry in visual search. *Spatial Vision, 17(4-5),* 443-464.

Roorda, A. & Williams, D. R. (1999). The arrangement of the three cone classes in the living human eye. *Nature397,* 520-522.

Rosch, E. (1975). The Nature of mental Codes for Color Categories. *Journal of Experimental psychology: Human perception and Performance, 1(4),* 303-322.

Rosch, E & Lloyd, B. B. (1978). *Cognition and categorization.* Hillsdale, NJ: Erlbaum.

Rosenblatt, F. (1961). *Principles of Neurodynamics: Perceptions and the Theory of Brain Mechanisms.* Washington, DC: Spartan.

Royden, C. S.,Wolfe, J. M. & Klempen, N. (2001). Visual search asymmetries in motion and optic flow fields. *Perception & psychophysics, 63(3),* 43-444.

van Rullen, R. (2003). Visual saliency and spike timing in the ventral visual pathway. *Journal of Physiology, 97,* 365-377.

van Rullen, R. & Koch. C. (2003). Competition and selection during visual processing of natural scenes and objects. *Journal of Vision, 3(1),* 75-85.

Rumelhart, D. E. (1970). A multicomponent theory of the perception of briefly exposed visual displays. *Journal of Mathematical Psychology, 7,* 191-218.

Saarinen, J. (1996). Target localisation and identification in rapid visual search. *Perception, 25,* 305-311.

Sagi, D. (1990). Detection of an orientation singularity in Gabor textures: Effects of signal density and spatial-frequency. *Vision Research, 30(9),* 1377-1388.

Sagi, D. & Julesz, B. (1985a). Fast noninertial shifts of attention. *Spatial Vision, 1,* 141-149.

Sagi, D. & Julesz, B. (1985b). "Where" and "what" in vision. *Science, 228,* 1217-1219.

Schendel, K. L., Robertson, L. C. & Treisman, A. (2001). Objects and their locations in exogenous cuing. *Perception & Psychophysics, 63(4),* 577-594.

Schmidt, T., Werner, S. & Diedrichsen, J. (2003). Spatial distortions induced by multiple visual landmarks: How local distortions combine to produce complex distortion patterns. *Perception & Psychophysics, 65(6),* 861-873.

Schwartz, S. & Loop, M. (1982). Evidence for transient luminance and quasi-sustained color mechanisms. *Vision Research, 22,* 445-447.

Seidenburg, M. (1987). Sublexical structures in visual word recognition: Access units or orthographic redundancy? In: M. Coltheart (ed.). *Attention and performance X1I,* (pp 245-263). Hillsdale, NJ: Erlbaum.

Selfridge, O. G. (1959). *Pandemonium: A paradigm for learning.* London: H.M. Stationary Office.

Sereno, A. B. & Maunsell, J. H. (1998). Shape selectivity in primate lateral intraparietal cortex. *Nature, 395(6701),* 444-445.

Sheth, B. R. & Shimojo, S. (2001). Compression of space in visual memory. *Vision Research, 41,* 329-341.

Shiffrin, R. M. & Schneider, W. (1977). Controlled and automatic human information processing: Perceptual learning, automatic attending, and a general theory. *Psychological Review, 84,* 127-190.

Shih, S. & Sperling, G. (1996). Is there feature-based attentional selection in visual search? *Journal of Experimental Psychology: Human Perception and Performance, 22(3), 758-779.*

Sidman, M. (1952). A note on functional relations obtained from group data. *Psychological Bulletin, 49,* 263-269.

Simon-Thomas, E. R., Brodsky, K., Willing, C., Sinha, R. & Knight, R. T. (2003). Distributed neural activity during object, spatial and integrated processing in humans. *Cognitive Brain Research, 16)3),* 457-467.

Smallman, H. S. & Boynton, R. M. (1990). Segregation of basic colour in an information display. *Journal of the Optical Society of America A, 7(10),* 1985-1994.

Smithson, H. E. (2005). Sensory, computational and cognitive components of human colour constancy. *Philosophical Transactions of the Royal Society B, 360,* 1329-1346.

Snowden, R. J. (1996). Texture segregation and visual search: A comparison of the effects of random variations along irrelevant dimensions. *Investigative Ophthalmology and Visual Science, 37 (ARVO Supplement).*

Snowden, R. J. & Braddick, O. J. (1991). The temporal integration and resolution of velocity signals. *Vision Research, 31(5),* 907-914.

Snyder, C. R. R. (1972). Selection, inspection and naming in visual search. *Journal of Experimental Psychology ,92,* 428-431.

Sperling, G. (1960). The information available in brief visual presentations. *Psychological Monographs: General and Applied, 74,* 1-29.

Sperling, G. (1963). A model for visual memory tasks. *Human Factors, 5,* 19-31.

Sperling, G. (1967). Successive approximations to a model for short-term memory. *Acta psychological, 27,* 285-292.

Sperling, G. & Reeves, A. (1980). Measuring the reaction time of an unobservable response: A shift of visual attention. In: R. Nickerson (Ed.), *Attention & performance V111* (pp. 347-360). Hillsdale, NJ: Erlbaum.

Steinman, S. B. (1987). Serial and parallel search in vision. *Perception, 16,* 389-398.

Sternberg, S. (1966). High-speed scanning in human memory. *Science, 153,* 652-654.

Stiles, W. S. (1949). Investigation of the scotopic and trichromatic mechanisms of vision by the two-colour threshold technique. *Révue d'Opt. 28,* 215-237. Reprinted in Styles, W. S. (1978). Mecahnisms of Colour Vision. London: Academic Press.

Sundet, J. M. (1976). Effects of colour on perceived depth: Review of experiments and evaluation of theories. *Scandinavian Journal of Psychology, 19(1),* 133-143.

Tassinari, G., Aglioto, S., Chelazzi, L., Peru, A. & Berlucchi, G. (1994). Do peripheral non-informative cues induce early facilitation of target detection? *Vision Research, 34,* 179-189.

Theeuwes, J. (1990). Perceptual selectivity is task dependent: Evidence from selective search. *Acta Psychologica, 74,* 81-99.

Theeuwes, J. (1992). Perceptual selectivity for color and form. *Perception & Psychophysics, 51,* 599-606.

Thomas, J. P., Padilla, G. J. & Rourke, D. L. (1969). Spatial interactions in identification and detection of compound visual stimuli. *Vision Research, 9(2),* 283-292.

Thornton, T. L. & Gilden, D. L. (2007). Parallel and Serial Processes in Visual Search. *Psychological Review, 114(1),* 71-103.

Tipper, S. P., Weaver, B., Jerreat, L. M. & Burak, A. L. (1994). Object-based and environment-based inhibition of return of visual attention. *Journal of Experimental Psychology: Human Perception and Performance, 20(3),* 478-499.

Todd, S. & Kramer, A. F. (1994). Attentional misguidance in visual search. *Perception & Psychophysics, 56,* 198-210.

Toet, A. & Levi, D. M. (1992). The two-dimensional shape of spatial interaction zones in the parafoveal. *Vision Research, 32,* 1349-1357.

Toms, M., Morris, N. & Foley, P., (1994). Characteristics of visual interference with visuospatial working memory. *British Journal of Psychology, 85,* 131-144.

Townsend, J. T. (1969). *Mock parallel and serial models and experimental detection of these.* Paper presented at the Purdue Centennial Symposium on Information Processing.

Townsend, J. T. (1971). A note on the identification of parallel and serial processes. *Perception and Psychophysics, 10,* 161-163.

Townsend, J. T. (1976). Serial and within-stage independent parallel model equivalence on the minimum completion time. *Journal of Mathematical Psychology, 14,* 219-239.

Townsend, J. T. (1990). Serial and parallel processing: Sometimes they look like Tweedledum and Tweedledee but they can (and should) be distinguished. *Psychological Science, 1,* 46-54.

Townsend, J. T. & Ashby, F. G. (1983). *The stochastic Modelling of elementary psychological processes*. Cambridge: Cambridge University Press.

Townsend, J. T. & Fifeć, M. (2004). Parallel versus serial processing and individual differences in high-speed search in human memory. *Perception & Psychophysics, 66(6),* 953-962.

Treisman, A. (1964). Verbal cues, language and meaning in selective attention. *American Journal of Psychology, 77,* 206-219.

Treisman, A. (1977). Focussed attention in the perception and retrieval of multidimensional stimuli. *Perception & Psychophysics, 22,* 1-11.

Treisman, A. (1982). Perceptual grouping and attention in visual search for features and for objects. *Journal of Experimental Psychology: Human Perception and Performance, 8,* 194-214.

Treisman, A. (1985). Preattentive processing in vision. *Computer Vision, Graphics, and Image Processing, 31,* 156-177.

Treisman, A. (1986). Features and Objects on Visual Processing. *Scientific American, 255(5), 106-116.*

Treisman, A. (1988). Features and objects: the fourteenth Bartlett Memorial Lecture. *Quarterly Journal of Experimental Psychology, 40A,* 201-237.

Treisman, A. (1991). Search, similarity and integration of features between and within dimensions. *Journal of Experimental Psychology: Human Perception and Performance, 17,* 652-676.

Treisman, A. (1992). Spreading suppression or feature integration? A reply to Duncan & Humphreys (1992). *Journal of Experimental Psychology: Human Perception and Performance, 18(2),* 589-593.

Treisman, A. (1993). The perception of features and objects. In A. Baddeley & L. Weiskrantz (Eds.). *Attention, selection, awareness and control,* (pp 5-35). Oxford: Clarendon Press.

Treisman, A. (1998). Feature binding, attention and object perception. *Philosophical Transactions of the Royal Society of London B, 353,* 1295-1306.

Treisman, A. (2006). How the deployment of attention determines what we see. *Visual Cognition, 14(4-8),* 411-443.

Treisman, A. & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12,* 97-136.

Treisman, A. & Gormican, S. (1988). Feature analysis in early vision: Evidence from search asymmetries. *Psychological Review, 95, 15-48.*

Treisman, A. & Patterson, R. (1984). Emergent features, attention and object perception. *Journal of Experimental Psychology: Human Perception and Performance, 10,* 12-31.

Treisman, A. & Sato, S. (1990). Conjunction search revisited. *Journal of Experimental Psychology: Human Perception & Performance, 16,* 459-478.

Treisman, A. & Schmidt, H. (1982). Illusory conjunctions in the perception of objects. *Cognitive Psychology, 14,* 107-141.

Treisman, A. & Souther, J. (1985). Search asymmetry: a diagnostic for preattentive processing of separable features. *Journal of Experimental Psychology: General, 114,* 285-310.

Treisman, A., Sykes, M. & Gelade, G. (1977). Selective attention and stimulus integration. In S. Dornic (Ed), *Attention and PerformanceVI* (pp. 333-361). Hillsdale, NJ: Lawrence Erlbaum Associates.

Treisman, A., Vieira, A., & Hayes, A. (1992). Automaticity and preattentive processing. Special Issue: Views and varieties of automaticity. *American Journal of Psychology, 105,* 341-362.

Troscianko, T. S., Davidoff, J., Humphreys, G., Landis, T., Fahle, M., Greenlee, M., Brugger, P. & Phillips, W. (1995). Human colour discrimination based on a non-parvocellular pathway. *Current Biology, 6(2),* 200-210.

Tsal, Y. (1983). Movement of attention across the visual field. *Journal of Experimental Psychology: Human Perception & Performance, 9,* 523-530.

Tsal, Y. (1989). Do illusory conjunctions support the feature integration theory? A critical review of theory and findings. *Journal of Experimental Psychology: Human Perception and Performance,15,* 394-400.

Tsal, Y. & Baraket, T. (2005). Localization judgements under various levels of attention. *Psychonomic Bulletin & Review, 12(3),* 559-566.

Tsal, Y. & Lamy, D. (2000). Attending to an object's color entails attending to its location: Support for location-special views of visual attention. *Perception & Psychophysics, 62,* 960-968.

Tsal, Y. & Lavie, N. (1988). Attending to color and shape: the special role of location in selective visual processing. *Perception & Psychophysics, 44,* 15-21.

Tsal, Y. & Makovski, T. (2006). The Attentional White Bear Phenomenon: The Mandatory Allocation of Attention to Expected Distractor Locations. *Journal of Experimental Psychology: Human Perception and Performance, 32,* 351-363.

Tsal, Y. & Meiran, N. (1993). *Toward a resolution theory of visual attention.* Paper presented at the 34th Annual Meeting of the Psychonomic Society, Washington, DC.

Tsal, Y., Meiran, N. & Lavie, N. (1994). The role of attention in illusory conjunctions. *Perception & Psychophysics, 55(3),* 350-358.

Tsal, Y., Meiran, N. & Lamy, D. (1995). Towards a resolution theory of visual attention. *Visual Cognition, 2(2/3),* 313-330.

Tsal, Y. & Shalev, L. (1996). Inattention magnifies perceived length: The attentional receptive field hypothesis. *Journal of Experimental Psychology: Human Perception and Performance, 22,* 233-243.

Tsotsos, J. K., Culhane, S. N., Wai, W. Y. K., Lai, Y., Davis, N. & Nuflo, F. (1995). Modeling visual attention via selective tuning. *Artificial Intelligence, 78,* 507-545.

Turatto, M. & Galfano, G. (2000). Color, form and luminance capture attention in visual search. *Vision Research, 40,* 1639-1643.

Turatto, M. & Galfano, G. (2001). Attentional capture by color without any relevant attentional set. *Perception & psychophysics, 63(2),* 286-297.

Turvey, M. T. & Kravetz, S. (1970). Retrieval from iconic memory with shape as the selection criteria. *Perception & Psychophysics, 8,* 171-172.

Uddin, M. K., Ninose, Y. & Nakamizo, S. (2004). Accuracy and precision of spatial localization with and without saccadic eye movements: A test of the two-process model. *Psychologia, 47,* 28-34.

Ungerleider, L. G. & Mishkin, M. (1982). Two cortical visual systems. In D.J. Ingle, M. A. Goodale & R. J. Mansfield. *Analysis of visual behaviour* (pp 549-580). Cambridge, MA: MIT Press.

Valdes, L. A. (1993). *The relation of negative priming to interference.* Unpublished doctoral dissertation, Adelphi University, Garden City, NY.

Vecera, S. P. & Rizzo, M. (2004). What are you looking at? Impaired 'social attention' following frontal-lobe damage. *Neuropsychologia, 42(12),* 1657-1665.

Virzi, R. A. & Egeth, H. E. (1984). Is meaning implicated in illusory conjunctions. *Journal of Experimental Psychology: Human Perception and Performance, 10(4),* 573-580.

Volbrecht, V. J., Nerger, J. L. & Harlow, C. E. (1997). The Bimodality of Unique Green Revisited. *Vision Research, 37(4),* 407-416.

Vorberg, D. (1977). *On the equivalence of parallel and serial models of information processing.* Paper presented at the 10th annual mathematical psychology meetings: Los Angeles.

Vos, J. J. (1986). Are unique and invariant hues coupled? *Vision Research, 26,* 337-342.

Wandell, B. A., Brewer, A. A. & Dougherty, R. F. (2005). Visual field map clusters in human cortex. *Philosophical Transactions of the Royal Society B, 360,* 693-707.

Wandell, B. A., Dumoulin, S. O. & Brewer, A. A. (2007). Visual field maps in human cortex. *Neuron, 56(2),* 366-383.

Ward, R. & McClelland, J. L. (1989). Conjunctive search for one and two identical targets. *Journal of Experimental Psychology: Human Perception & Performance, 15(4),* 664-672.

Warrington, E.K., (1985). Agnosia: The impairment of object recognition. In P. J. Vinken, G. W. Bruyn & H. L. Klawans (Eds.). *Handbook of Clinical Neurology.* Amsterdam: Elsevier.

Watamaniuk, S. N. J. & Duchon, A. (1992). The human visual system averages speed information. *Vision Research, 32,* 931-941.

Watermaniuk, S. N. J., Sekulaer, R. & Williams, D. W. (1989). Direction perception in complex dynamic displays: the integration of direction information. Vision Research, 29, *47-59.*

Watson, D. G., & Humphreys, G. W. (1997). Visual marking: Prioritizing selection for new objects by top-down attentional inhibition of old objects. *Psychological Review, 104,* 90-122.

Watson, D. G. & Humphreys, G. W. (1998). Visual marking of moving objects: A role for top-down feature based inhibition in selection. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 946-962.

Watson, D. G. & Humphreys, G. W. (2000). Visual marking: Evidence for inhibition using a probe-dot detection paradigm. *Perception & Psychophysics, 62(3),* 471-481.

Weal, R. A. (1964). When red turns to green. *Nature, 201,* 661-663.

Weichselgartner, E., & Sperling, G. (1987). Dynamics of automatic and controlled visual attention. *Science, 238,* 778-780.

Weitzman, D. O. & Kinney, J. A. S. (1967). Appearance of Color for Small, Brief, Spectral Stimuli, in the Central Fovea. *Journal of the Optical Society of America, 57(5),* 665-670.

Werner, S. & Diedrichsen, J. (2002). The time course of spatial memory distortions. *Memory & Cognition, 30,* 718-730.

Westheimer, G. & McKee, S. P. (1977). Spatial configurations for visual hyperacuity. *Vision Research, 17,* 941-948.

Wheeler, M. E. & Treisman. A. M. (2002). Binding in Short-Term Memory. *Journal of Experimental Psychology: General, 131(1),* 48-64.

Wickins, C., Andre, A. (1990). Proximity compatibility and information display: Effects of colour, space and objectness on information integration. *Human Factors,* Vol 32, pp 97-136.

Wilkinson, F., Wilson, H. R. & Ellemberg, D. (1997). Lateral interactions in peripherally viewed texture arrays. *Journal of the Optical Society of America A, 14,* 2057-2068.

Williams, D. W. & Sekuler, R. (1984). Coherent global motion percepts from stochastic local motion. *Vision Research, 24,* 55-62.

Willmer, E. N. (1944). Colour of Small Objects. *Nature, 153, 774*-755.

Wolfe, J .M. (1992). "Effortless" texture segmentation and "parallel" visual search are *not* the same thing. *Vision Research, 32(4),* 757-763.

Wolfe, J. M. (1994). Guided Search 2.0: A revised model of visual search. *Psychonomic Bulletin and Review, 1,* 202-238.

Wolfe, J. M. (1998). Visual Search. In: H. Pashler (Ed). (1998). *Attention,* pp 13-74. Hove: Psychology Press.

Wolfe, J. M. (2003). Moving towards solutions to some enduring controversies in visual search. *Trends in Cognitive Sciences, 7(2),* 70-76.

Wolfe J. M., & Cave K. R. (1999). The psychophysical evidence for a binding problem in human vision. *Neuron, 24,* 11-17.

Wolfe, J. M., Cave, K. R., & Franzel, S. L. (1989). Guided search: An alternative to the feature integration model for visual search. *Journal of Experimental Psychology: Human Perception & Performance, 15,* 419-433.

Wolfe, J. M., Yu, K. P., Stewart, M. I., Shorter, A. D., Freidman-Hill, S.R. & Cave, K. R. (1990). Limitations on the parallel guidance of visual search: Color x color and orientation x orientation conjunctions. *Journal of Experimental Psychology: Human Perception and Performance, 16(4),* 879-892.

Wolff, P. (2004). Position of code and code for position: From isomorphism to a sensorimotor account of space perception. *Visual cognition 11(2/3),* 137-160.

Wolford, G. (1975). Perturbation model for letter identification. *Psychological Review, 82,* 184-199.

Wolford, G. & Shum, K. H. (1980). Evidence for feature perturbations. *Perception & Psychophysics, 27,* 409-420.

von Wright, J. M. (1968). Selection in immediate visual memory. *Quarterly Journal of Experimental Psychology, 20,* 62-68.

Yantis, S. & Egeth, H. E. (1999). On the distinction between visual salience and stimulus-driven attentional capture. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 661-676.

Zeki, S. (2001). Localization and globalization in conscious vision. *Annual Review of Neuroscience, 24,* 57-86.

Zeki, S M., Watson, J. D. G., Leuck C. J., Friston, K. J., Kennard, C. & Frackowiak, R. S. J. (1991). A direct demonstration of functional specialization in human visual cortex. *Journal of Neuroscience, 11,* 641-649.

Zohary, E. & Hochstein, S. (1989). How serial is serial processing in vision? *Perception, 18,* 191-200.